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Biological synopsises for three exotic molluscs, Manila Clam (*Venerupis philippinarum*), Pacific Oyster (*Crassostrea gigas*) and Japanese Scallop (*Mizuhopecten yessoensis*) licensed for Aquaculture in British Columbia.

Sommaires biologiques pour trois mollusques exotiques, Palourde Japonaise (*Venerupis philippinarum*), Huître Creuse du Pacifique (*Crassostrea gigas*) et Pétoncle Japonais (*Mizuhopecten yessoensis*) pour lesquels on a accordé un permis d'aquaculture en Colombie-Britannique

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ABSTRACT

This document provides synopses of biological information on three mollusc species utilized for aquaculture in British Columbia: Manila clam, Pacific oyster and Japanese scallop. The synopses are designed to meet the information needs for risk assessment under the National Code on Introductions and Transfers of Aquatic Organisms. Information from the literature on taxonomy, distribution, biology, health and ecology is summarized for each species. Where available other information required for assessment under the National Code is provided. This information is intended to contribute to the assessment of transfers required for expansion of shellfish aquaculture beyond the current range of these species in British Columbia and to assess the utility of current Introduction and Transfer Zones in light of each species' distribution and potential for dispersal. Recommendations include conducting formal risk assessments for these species to evaluate information needs and identify gaps for future assessments and developing synopses for other non-indigenous culture species and high-priority indigenous species under consideration for aquaculture.

RÉSUMÉ

Le présent document propose des sommaires de renseignements biologiques sur trois espèces de mollusques destinés à l'aquaculture en Colombie-Britannique, la palourde japonaise, l'huître creuse du Pacifique et le pétoncle japonais. Les sommaires en question doivent répondre aux besoins de renseignements visant les évaluations du risque faites en vertu du Code national sur l'introduction et le transfert d'organismes aquatiques. Des renseignements provenant de documents sur la taxinomie, la répartition, la biologie, la santé et l'écologie sont résumés pour chaque espèce. Le cas échéant, on peut obtenir d'autres renseignements nécessaires aux évaluations faites en vertu du Code national. Ces renseignements doivent servir aux évaluations de transferts nécessaires à la croissance de la conchyliculture au-delà de l'aire de répartition actuelle en Colombie-Britannique et à évaluer l'utilité actuelle des zones d'introduction et de transfert en fonction de la répartition et de la dispersion possible de chaque espèce. Les recommandations portent en outre sur l'exécution d'évaluations du risque formelles pour ces espèces, afin de déterminer les besoins en renseignements et les lacunes aux fins d'évaluations futures, et sur l'élaboration de sommaires pour d'autres espèces non indigènes et indigènes prioritaires envisagées pour l'aquaculture.

INTRODUCTION

BACKGROUND

The British Columbia shellfish culture industry is primarily based on species exotic to the Region. The industry is growing and there is increasing interest in adding both exotic and indigenous species to the aquaculture activities.

The industry routinely relies on importation of juveniles for outplanting onto leases and there is also considerable interest in extending the range of the exotic species already cultured in BC to more northern areas and to use different culture methods.

All introductions and transfers of live aquatic animals have potential impacts on their receiving environment and the species living in that environment. Under the Rio Convention on Biological Diversity (http://www.biodiv.org/convention/default.shtml), signed by Canada, impacts on the biodiversity need to be considered. Transfer or introduction of species may result in alterations to natural ecosystems, genetic changes in indigenous populations, and there could be risks to the health of indigenous populations from introduction of pathogens or parasites. As well there could be non-target species (fellow travellers) accompanying the shipment.

The National Code on Introductions and Transfers of Aquatic Organisms (DFO 2003 http://www.dfo-mpo.gc.ca/science/aquaculture/code/prelim_e.htm) provides a mechanism, through Regional Introductions and Transfers Committees, to have a consistent process to assess introductions and transfers of fish, including shellfish and crustaceans (*fish* as defined by the *Fisheries Act*). The Code which was approved by all Provinces and Territories through the Canadian Council of Fisheries and Aquaculture Ministers provides direction on information requirements and decision rules for completion of a risk assessment for fish movements. In British Columbia, the requirement for risk assessment is also included in the draft Guidelines for Shellfish Introductions and Transfers in British Columbia, produced by the Federal/Provincial Introductions and Transfers Committee (ITC 2004).

To date only very few risk assessments have been carried out. All of these were done on a on a case-by-case basis, often in view of considerable information gaps through lack of relevant scientific material. In this paper, the authors have used information available for three exotic species which were introduced into BC years ago (since the early 1900s for Pacific oysters, *Crassostrea gigas*, and for nearly 2 decades for Japanese scallops, *Mizuhopecten yessoensis*, long before the requirements of risk assessments) and for which there is a significant amount of peer reviewed scientific literature. This paper compiles the biological information available on Manila clam, *Venerupis philippinarum*; Pacific oyster; and Japanese scallop, all of which are important species for aquaculture production. It also reviews the known impacts of these species in their "new" environment and on indigenous species. As a next step, this information should be used to complete a risk assessment as proscribed by the National Code. It is anticipated that through this two-step process a model can be established for the type and detail of information required for future reviews to assess impacts of other exotic species that may become of interest to the aquaculture industry.

The current paper is also thought to be of interest to assess shellfish aquaculture activities which are rapidly expanding beyond the Strait of Georgia to the west coast of Vancouver Island and BC's northern coastal areas. Many of these aquaculture tenures are established to culture exotic species. Fisheries and Aquaculture Management (FAM) and ITC staff have received applications to move exotic species to various areas or zones of the coast and have had to make decisions with little or no data. There have been questions and concerns regarding the range of exotics already naturalised in BC and potential impacts on fish habitat, indigenous species health and genetics, and the ecosystem.

The BC aquaculture industry also has an interest in the culture of indigenous species (e.g., geoducks, *Panopea abrupta*; cockles, *Clinocardium nuttallii*). A number of questions, especially regarding genetic impacts on local stocks in the receiving area, will need to be added to the topics covered by the information on exotic species presented here. Future papers may need to deal with that subject, including determining information gaps to be filled before large-scale introduction/transfer projects are undertaken.

OBJECTIVES

Specific objectives for this paper are:

1. To summarize for each species from the literature: taxonomy; description; history in aquaculture, enhancement or other introductions; life history; native range, previous introductions and associated ecological effects; limiting factors within the natural range; physiological tolerances; habitat preferences; reproductive biology; migratory behaviour; food preferences; growth rate and life span; pathogens and parasites.
2. Where information exists, address other elements of the National Code risk assessment framework, in particular: potential for survival and establishment in the event of escape; habitat occupation and overlap with vulnerable, threatened or endangered species; niche overlap with native species; trophic relations and impacts of the introduced species; potential for survival and reproduction in receiving environment; potential for hybridization; potential for local extinction of native species of stocks due to introduction.
3. Provide information in a format that can be tested through risk assessment procedures defined in the National Code in order to identify a model that can be employed for developing biological synopsises for the other species of interest to aquaculture in BC.

METHODS

Taxonomy follows Coan *et al.* (2000), which was also the primary source for information on synonymy within North America. Additional synonyms from elsewhere in the world were collected from various sources (Abbott 1974, Carriker and Gaffney 1996), but may be incomplete. Common names were taken from various literature sources, but those deemed official by Turgeon *et al.* (1998) are in bold type in the summary tables.

Information on the species-specific licensing of aquaculture tenures is summarized from BC Ministry of Agriculture and Lands reports to shellfish processors (for February 2006). It is important to note that although an aquaculture site may be licensed for a species, there may be none growing on the site, and in fact transfer of the species to the site may not be approved or licensed by the ITC. Records of introductions and transfers are from the Introductions and Transfers Committee database. Definitions of Shellfish Transfer Zones (STZs) are from ITC (2004) and are summarized in Table 1 and Figure 1. Pacific Fishery Management Areas (PFMAs) are shown in Figure 2. Sea surface temperature data were summarized from DFO Ocean Sciences database available at; www.pac.dfo-mpo.gc.ca/sci/osap/data/SearchTools/Searchlighthouse_e.htm.

Information on pathogens and parasites is clustered to present exotic species first and then information on species known to occur in BC. For this review, pathogens are defined as organisms known to cause serious disease (including gross signs of infection that affect market value, morbidity and mortalities) in the bivalve host being discussed. Parasites are organisms that can inhabit the bivalve in question but are not known to cause a significant disease in that host. If the prevalence of infection in a population is always low according to all available records, the organism is grouped with the parasites even if the resulting disease is significant to the infected individual. Pathogens and parasites are classified as exotic, *i.e.*, known from a particular host species eslewhere in the world but not British Columbia, and enzootic, *i.e.*, those which have been reported from the host species in British Columbia.

RESULTS

MANILA CLAM

Taxonomy

The Manila clam continues to suffer taxonomic confusion in even the most recent literature. The common name accepted by the American Fisheries Society in the United States is Japanese littleneck (Turgeon *et al.* 1998, Coan *et al.* 2000), although the vernacular Manila clam is commonly used in Canada and Pacific Northwest states. Some agency documents and websites refer to this species as Manila littleneck. The accepted scientific name is *Venerupis* (*Ruditapes*) *philippinarum* (A. Adams and Reeve, 1850). However, the species still appears in recent literature as *Ruditapes philippinarum* in China (*e.g.*, Wang *et al.* 2005), France (Baudrimont *et al.* 2005), Hong Kong (*e.g.*, Ng and Wang 2004), Italy (*e.g.*, Garcia-Lavandeira *et al.* 2005), Japan (*e.g.*, Saito *et al.* 2004), Korea (*e.g.*, Park and Choi 2004), Spain (*e.g.*, Riba *et al.* 2004) and the United States (*e.g.*, Ruesink *et al.* 2006); and as *Tapes philippinarum* in Canada (*e.g.*, Munroe *et al.* 2004), England (*e.g.*, Jensen *et al.* 2004), Italy (*e.g.*, Meneghetti *et al.* 2004), Korea (*e.g.*, Kang and Kim 2004) and Spain (*e.g.*, Matozzo and Marin 2005). This species has also historically been reported under the trivial name *semidecussata* (*e.g.*, Liang *et al.* 1987) and was previously assigned to the trivial name *japonica* (*e.g.*, Chew 1989; Quayle and Bourne 1972). Coan *et al.* (2000) listed 11 junior synonyms and one subspecies that is no longer valid (Table 2), with the comment that additional synonyms were known from western Pacific literature.

Description

Manila clams are generally longer than they are high, resulting in an oblong profile (as compared to the more circular profile of the native littleneck clam, *Protothaca staminea*)(Figure 3). The valves are thick and marked with both radial and concentric sculpture with the radial striae more pronounced on the posterior part of the valves. A lunule is present as a flat area or depressed pit anterior to the umbo and lacks the ridge present in *P. staminea*. The inner margin of the shell is smooth and lacks crenulations on the ventral margin that are present in the native littleneck clam. The interior of the valves is white or yellow with deep purple at the posterior end. The outer surface of the valves varies from uniform gray or brown to brightly coloured individuals with two red radial markings surrounded by darker blue. Larger animals are generally less colourful. Maximum size is approximately 75 mm (Quayle 1960; Quayle and Bourne 1972; Abbott 1974; Kozloff 1996; Harbo 1997; Coan *et al.* 2000).

Distribution

Native Range

The native range of *V. philippinarum* is the western Pacific from the Kuril Islands, Sakhalin Island, and Russia, through Japan and Korea to China and Hong Kong (Lee 1996; Coan *et al.* 2000; Ivanova *et al.* 2001; Kulikova and Sergeenko 2003; Selin and Dolganova 2003).

Introductions

Manila clams were unintentionally introduced to Ladysmith Harbour, BC, with Pacific oyster seed in the 1930s where they were initially described as a new species, *Paphia bifurcata* (Quayle 1938, 1941). They quickly spread through the Strait of Georgia (Neave 1949) and the west coast of Vancouver Island from Barkley Sound to Esperanza Inlet (Quayle 1964). Carlton (1979) indicated that Manila clams were found throughout the southern Strait of Georgia by the mid-1940s and to Jervis Inlet and Cortes Island prior to 1950. Bourne (1979) implied that Manila clams had made their way to the west coast of Vancouver Island with Pacific oysters; Manila clams had spread at least as far as Esperanza Inlet in the 1950s (Quayle 1960) and were found in Quatsino Sound in the 1960s (Quayle and Bourne 1972; Bourne 1979, 1982, 1997).

There are currently 284 tenures licensed for the culture of Manila clams in BC (Table 3). Most of these (234) are in Shellfish Transfer Zone (STZ) 4 and over 100 are in Pacific Fisheries Management Area (PFMA) 14 on the east coast of Vancouver Island, which includes Baynes Sound. Records of ITC transfer permits show that 399 introductions of hatchery stock occurred in BC from 1982-2005 (Table 4). The vast majority of these were into the Strait of Georgia (STZ 4).

Manila clam stocks on the west coast of Vancouver Island are well established and of sufficient abundance and productivity to support large commercial fishery landings in addition to recreational and First Nations utilization (Bourne and Farlinger 1982; Adkins and Harbo 1991). Recent exploratory surveys showed Manila clams to be abundant on selected beaches in Barkley, Clayoquot and Kyuquot Sounds and in Winter Harbour, Klaskino and Ououkinsh Inlets (Table 5; Gillespie and Bourne 2005a; Gillespie *et al.* 2004). They were less abundant in Esperanza, Nasparti and Klaskish Inlets and a survey in 1993 found them to be present at low densities in Quatsino Sound (Bourne and Heritage 1997).

Manila clams were reported from the North Coast of BC at Spider Anchorage in 1972 and the Bella Bella area in 1980 (Bourne 1979, 1982). Numerous exploratory surveys between 1990 and 2004 documented widespread and abundant Manila clam populations in PFMA 7 (Table 5; Bourne and Cawdell 1992; Bourne *et al.* 1994; Heritage *et al.* 1998; Gillespie and Bourne 2000, 2005b; Gillespie *et al.* 2004) and a fishery was developed in 1992 that continues to the present (Gillespie *et al.* 1999a, 2001).

Exploratory surveys did not locate Manila clams in PFMA 1 through 5 (Table 5; Bourne and Cawdell 1992; Gillespie and Bourne 1998, 2000; Gillespie 2007). Manila clams were present at low to moderate abundances on selected beaches in PFMA 6 (Bourne and Cawdell 1992; Heritage *et al.* 1998; Gillespie and Bourne 2000, 2005b; Gillespie *et al.* 2004).

The current northern limit in the eastern Pacific is Laredo Inlet, BC (Gillespie and Bourne 2000, Gillespie *et al.* 2004). Attempted introductions further north in Massett Inlet and Naden Harbour in 1962 and Cosine Island in 1969 were not successful (Bourne 1979, 1982; Gillespie and Bourne 1998, 2000)[1].

On the west coast of the United States, Manila clams are found in Puget Sound, Grays Harbour and Willapa Bay, Washington, and from Humboldt Bay to Elkhorn Slough in California (Coan *et al.* 2000; Wasson *et al.* 2005). The intimation of Nosho and Chew (1972) that Manila clams occurred in Southeast Alaska are either in error or a misinterpretation of an adventitious record (Carlton 1979).

Streftaris *et al.* (2005) indicated that Manila clams had been introduced to all the major seas of Europe (Arctic, Atlantic, Baltic, Black, Mediterranean and North) but did not specifically indicate where naturalized populations had become established (Table 6). Manila clams were introduced to Ireland (in 1982; Xie and Burnell 1994) and other areas of the U.K. (Spencer *et al.* 1991) and a naturally sustained population exists in Poole Harbour (Morgan 2003, Jensen *et al.* 2004). Albayrak *et al.* (2001) documented specimens collected at Bozcaada, Turkey, indicating that the species has spread to the Aegean Sea. They were introduced to the Atlantic and Mediterranean coasts of France (late 1960s), Spain, Italy (in 1983), Germany, Tunisia, Belgium and Israel (Ponurovsky and Yakolev 1992). Manila clams became established in France and, in at least one instance, have completely replaced the native *Venerupis decussata* (Goulletquer *et al.* 1998; Blanchet *et al.* 2004). They have become well established on the Adriatic coast of Italy, where they greatly outnumber but have not replaced *V. decussata* (Ambrogi 1998; Breber 2002). Manila clams were introduced to Norway in 1987 and outplanted to at least six sites (Hopkins 1998; Mortensen and Strand 2000). Four of these sites were surveyed in 1995 and 1996 and several Manila clams were found to have survived and spawned, but there was no evidence of successful breeding.

Manilas were introduced to the island of Oahu in Hawaii at Kalihi Bay, Pearl Harbour and Kaneohe Bay between 1918-1920 and naturally sustained populations still exist in Kaneohe Bay and Pearl Harbour (Yap 1977; Coles *et al.* 1999, 2002). They have also been introduced to Tahiti and the US Virgin Islands (Ponurovsky and Yakolev 1992).

Habitat Preferences

Manila clams are found in the upper half of the intertidal zone in substrates of gravel, sand and mud, primarily in inside or protected waters (Quayle 1960). Because their siphons are short, they live in shallow (maximum 10 cm depth, Harbo 1997), transitory burrows in the substrate and are susceptible to extremes of temperature, including catastrophic mortalities termed "winter kills". These can occur when night-time low tides coincide with low air temperatures and prevailing winds (Bower *et al.* 1986; Bower 1992a).

Physical Tolerances

It is common for the early embryos and larvae of bivalve mollusks to have narrower environmental requirements than adults (Malouf and Bricelj 1989). Malouf and Bricelj (1989) reported thermal tolerances of 4-30°C for adult Manila clams and 14-27°C for larvae. Chew (1989) reported temperature tolerance for larval Manila clams as 0-36°C with the optimum being

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[1] Eight specimens from the southern Queen Charlotte Islands (Burnaby Narrows and Murchison-Faraday Passage) attributed to this species (Sloan *et al.* 2001) were re-examined at the Royal BC Museum and found to be small *Protothaca staminea*. An anecdotal record of Manila clams north of Prince Rupert at Pearl Harbour, was not verified by voucher specimens or by brief visits by DFO staff to the area on at least three occasions.

23-24°C. Ohba (1959) reported decreased size and lifespan in natural populations where temperatures exceeded 15°C for much of the year, exceeded 20°C for four months of the year and reached a maximum of 26°C. Holland and Chew (1974) reported broader ranges of size and age in a natural population where temperatures exceeded 15°C for four months of the year, but only exceeded 20°C for limited periods. Mann (1979) reported increased mortality and decreased dry meat weight in clams maintained at 21°C, coincident with the onset of spawning. This led Mann to postulate that large animals suffered a large negative energy balance under conditions of temperature stress (>20°C) post-spawning. Shpigel and Fridman (1990) reported good growth, spawning and low mortality for Manila clams grown at mean monthly temperatures of 13-23°C (range 11-31°C) in Israel.

Minimum temperature required for gonadal activation was 8°C (Mann 1979; Bourne 1982). Minimum temperature required for gonadal development was 12°C and for spawning was 14°C (Mann 1979). Helm and Pellizzato (1990) reported commencement of gonad maturation at 8-10°C and spawning at 20-31°C in Italian hatcheries.

Manila clams are euryhaline and occur throughout a wide range of salinities. Haderlie and Abbott (1980) reported that Manila clams were tolerant of salinities 30-50% of pure seawater. Malouf and Bricelj (1989) reported salinity tolerance for adult Manila clams to be 14-35‰. Chew (1989) reported salinity tolerances of 13.5-35‰ for adult Manila clams with the optimum being 24-32‰. Elston *et al.* (2003) reported that salinities ≤10‰ were lethal to adult clams and that 12.5‰ was marginal for survival; they also noted that mortality rate may depend in part on the rate at which they are re-acclimated to higher salinities. Manila clams grown in mariculture pond effluent in Israel survived well and grew in a salinity of 41‰ (Shpigel and Fridman 1990).

In a hatchery setting, salinities of 25-35‰ are recommended; although juveniles and adults can tolerate greater or lesser salinities for short periods of time, larvae and newly settled seed cannot (Helm and Pellizzato 1990). Malouf and Bricelj (1989) did not report a range for larvae, only stating that rearing had been successful at 35‰. Larvae held at 8‰ failed to survive, those held at 12‰ survived but did not behave normally, while larvae held at ≥15.5‰ behaved and survived like larvae held at higher salinities (Numaguchi 1998, cited in Elston *et al.* 2003).

Fertilized eggs developed best at salinities of 26-33‰ and temperatures of 18-23°C, although the optimal temperature was stated to be 23-26°C (Helm and Pellizzato 1990). Lower temperatures slowed development while higher temperatures increased bacterial infection. In Italian hatcheries, Manila clam larvae developed from D-hinge stage through veliger and pediveliger to settlement as spat in approximately 16 days at 25°C and 30-33‰ (Helm and Pellizzato 1990, their Figure 2). Size at settlement is approximately 190-235 µm (Chew 1989).

Reproductive Biology

Manila clams in British Columbia and Puget Sound begin gonadal development in the spring, with late active clams appearing in mid-April and ripe clams by mid-June (Holland and Chew 1974; Bourne 1982). Spawning began in Puget Sound in late May and peaked in August, and began in June in BC as larvae were found in plankton samples taken at the end of June. Spawning ended in October-November, when temperatures declined, and partially spawned individuals resorbed residual gametes. Spawning occurs over several months with two peaks of settlement observed in Puget Sound; a minor event in July and a major event in September (Williams 1978; Bourne 1982).

Manila clams are reported to spawn once a year in northern Japan, twice a year (late spring and early-late fall) in southern Japan, twice a year in Italy and France, and three times a year in

Spain (Ohba 1959; Yamamoto and Iwata 1956; Bourne 1982; Beninger and Lucas 1984; Xie and Burnell 1994; Breber 2002). Ponurovsky and Yakolev (1992) reported spawning periods of May-August in southwestern Russia, June-August in Hokkaido, February-May and July-December in southern Japan, May-August in Korea, September-December in China, May-September in France, February-April and August-September or November-December in US Virgin Islands, and year-round in Israel and Hawaii. Clams that were ripe year-round in the US Virgin Islands and Israel were cultured at relatively high temperatures and constant food supplies (Rodde *et al.* 1976; Beninger and Lucas 1984; Shpigel and Fridman 1990).

Size at first maturity is considered to be 15-20 mm total length (TL), which corresponds to an age of approximately one year (Holland and Chew 1974). Some smaller clams (5-10 mm TL) developed sperm and oocytes but did not spawn.

There is evidence of serial hermaphrodism in Mania clams from Primorye, Russia on the northwest Sea of Japan (Ponurovsky and Yakolev 1992). Small clams (<15 mm TL) produced sperm in their first spawning season, the sexes were balanced in later spawnings and there was a larger proportion of females in older age classes of some populations. Helm and Pellizzato (1990) reported that Manila clams were protandric hermaphrodites with older clams either turning into females or remaining as functional males.

Partially spawned clams have been collected in northern BC as early as May (Table 7), although these may be clams that did not spawn the previous fall, did not fully resorb the unspawned gametes and overwintered in this condition (N.F. Bourne, DFO, pers. comm). Development is slower in Johnstone Strait and Quatsino Sound, as most clams were in late active or ripe stages in July. This is in contrast to Hood Canal, where peak spawning was recorded July through September (Holland and Chew 1974).

In Ireland, although adult clams were able to ripen, it was uncertain whether ripe gametes were released by spawning or resorbed (Xie and Burnell 1994). They also noted that spawning was delayed (peak spawning from September to February) due to low temperatures and that reproduction was not successful, likely because water temperatures post-spawning were not conducive to larval development. It is likely that delayed spawning in northern BC would result in larvae failing to develop due to low water temperatures in the fall.

Fecundity increases with size in Manila clams, with estimates ranging from 432,000 eggs (20 mm TL) to 2,350,000 eggs (40 mm TL)(Hawaii; Yap 1977), 188,000 eggs (19 mm TL) to 1,503,000 (42 mm TL)(China; Shi *et al.* 1984) and 945,000 (34 mm TL) to 11,794,000 (42 mm TL)(Korea; Park and Choi 2004).

Early Life History

Larval development requires approximately three weeks in BC (Bourne 1982) and two to four weeks in Washington State (Toba *et al.* 1992); exact duration depends on temperature and food supply. Larvae settle at sizes of 165-235 µm; they actively seek suitable substrate, attach with a byssal thread and undergo metamorphosis to an infaunal juvenile.

Growth Rate and Lifespan

Bourne (1982) calculated growth rates for Manila clams in different areas of BC. Growth was most rapid in the Strait of Georgia, followed by the west coast of Vancouver Island, the Central Coast and Queen Charlotte Strait. Manila clams reached the legal size limit (38 mm TL) in 3.5 years in the Strait of Georgia, 4.0 years on the west coast of Vancouver Island, 5.0 years in the

Central Coast and 5.5 years in Queen Charlotte Strait. Growth rates calculated from recent exploratory surveys provide similar information; legal size (38 mm TL) was attained after 3.5-6.0 years in PFMA 6 and 7, after 3.0-4.5 years in PFMA 8 through 11, after 3.5-6.5 years in Johnstone Strait (PFMA 12 and portions of 13), and 3.5-5.5 years on the west coast of Vancouver Island with growth being somewhat slower in some northern locations (Winter Harbour, Quatsino Sound and Ououkinsh Inlet) (Table 8). For comparative purposes, age to legal size was approximately 4.0-5.0 years in Clayoquot Sound (Bourne and Farlinger 1982), 3.5-5.3 for four beaches in southern Strait of Georgia (Gillespie and Bond 1997) and 4.0-6.5 years for Savary Island in the northern Strait of Georgia (Gillespie *et al.* 1998a).

Growth is rapid for the first 4-5 years and slower thereafter. Growth is dependent on substrate type and tidal height occupied on the beach, so growth rates often vary within populations on a given beach depending on where on the beach the clams are found.

Maximum size reported from BC is 79 mm TL, although most clams in a population are considerably smaller. Maximum age reported from BC is 14 years (Bourne 1987).

Under culture conditions, growth is much more rapid; Manila clams reached sizes of 38 mm TL in 13 months in an upwelling system in the US Virgin Islands (Rodde *et al.* 1976) and 30-35 mm TL in 16-18 months in a tray system in Israel (Shpigel and Fridman 1990).

Migratory Behaviour

Dispersal of Manila clams is only through pelagic larval stages. Settled juvenile and adult clams have limited capacity to move across the substrate and re-establish burrows, but populations on beaches separated by unsuitable habitat are closed except for immigration of new larval recruits (Glock and Chew 1979).

Because the larval period can last 3-4 weeks, depending on temperature, there is potential for larvae to be transported considerable distances by surface currents. From their discovery in Ladysmith Harbour in 1936, Manilas spread relatively quickly throughout the southern Strait of Georgia, reaching most sampled locations in less than ten years (Quayle 1964; Carlton 1979). Spread through the northern Strait of Georgia was achieved before 1950. Similarly, they spread up the west coast of Vancouver Island to Esperanza Inlet quickly, but took longer to be carried around Brooks Peninsula to Quatsino Sound, where they were found in 1966 (Bourne 1982). It must be noted, however, that dispersal of Manila clams in BC may not have been entirely through larval transport; the possibility exists that dispersal within BC was aided either through intentional transport or accidental transport of Manila clams with Pacific oysters.

Food Preferences

Manila clams are filter feeders, collecting microscopic prey and organic matter from the water column (Purchon 1968). Water is drawn into the mantle cavity through the inhalant siphon and food particles are collected on the ctenidia (gills) and moved to the mouth on ciliary strands of mucous. Materials that arrive at the mouth are sorted by the labial palps and either ingested or rejected and passed to the exhalent siphon. Feeding occurs only when the clam is immersed in water; when the tide recedes the valves are closed tightly and feeding is suspended until the tide covers the clam again (Cesari and Pellizzato 1990). Most of the respiratory exchange in filter feeding bivalve mollusks takes place through the mantle rather than the ctenidia (Purchon 1968; Cesari and Pellizzato 1990).

Unlike some bivalves that browse organic matter from the surface layers of the substrate (*e.g.*, *Tellina*, *Macoma*) or collect organic matter from deep in the substrate by pedal feeding (*e.g.*, *Lucina*, *Thyasira*, *Nuttallia*), adult Manila clams are obligate filter feeders (Purchon 1968, Gillespie *et al.* 1999b).

Pathogens and Parasites

Exotic Pathogens

Viral infections in bivalves are poorly understood and for most viral infections, the impact on hosts has not been specifically described. To date, viral infections have not been investigated in Manila clams from British Columbia. However, a herpes-like viral infection in larval *V. philippinarum* was associated with sporadic high mortalities in a commercial hatchery in France (Renault *et al.* 2001a,b).

Vibrio tapetis (cause of brown ring disease) adheres to and progressively colonizes the surface of the periostracal lamina at the mantle edge of the shell. The resulting disruption to the periostracal lamina causes the anomalous deposition of periostracum around the inner shell surface resulting in an accumulation of brown organic material which is symptomatic of the disease. Infection also disturbs the normal calcification process involved in shell deposition. Allam *et al.* (2002) concluded that clam mortality associated with brown ring disease likely resulted from the penetration of *V. tapetis* into the extrapallial space through disruption of the periostracal lamina. Since 1987, brown ring disease has been associated with mass mortalities on various cultured clam beds along the west coast of France (Paillard *et al.* 1994). Signs of this disease have not been reported in British Columbia but surveys to detect the presence of *V. tapetis* have not been conducted.

Perkinsus olseni is a protozoa that frequently induces the formation of visible milky white cysts or nodules on the gills, foot, gut, digestive gland, kidney, gonad and mantle of heavily infected clams. The sometimes massive aggregation of *P. olseni* and haemocytes form lesions that may interfere with respiration and other physiological processes such as reproduction (fertility/fecundity, when large lesions occur in the gonads), growth and/or survival and thus have an impact on fishery productivity. This parasite was considered as the cause of epizootic mortalities of *Venerupis philippinarum* in Korea (Park *et al.* 1999) and China (Liang *et al.* 2001) and the cause of population declines of this clam in Japan (Hamaguchi *et al.* 1998). Also, heavy infections observed in older clams in Korea appeared to cause retarded growth and delayed gamete maturation resulting in altered population dynamics and stability (Park and Choi 2001). To date, this parasite has not been detected in British Columbia.

Exotic Parasites

Unidentified haplosporidians have been reported from Manila clams in Europe and Japan. In Japan, a haplosporidian infection was detected in May 2002 in one of 40 Manila clams experimentally deployed in April 2002 (from Oita Prefecture, Japan) to investigate the drastic decrease in commercial *V. philippinarum* stocks in the area of Yamaguchi Prefecture. This is the only known case of this parasite in Japan. The gills and connective tissue of the visceral mass of the infected clam were almost completely replaced by plasmodia and spores with a few plasmodia also occurring in the foot tissues (Itoh *et al.* 2005). Although no mortalities have been attributed to these parasites, the effect on clam populations is unknown but, related species are highly pathogenic to oysters on the east coast of North America. To date this parasite has not been detected in British Columbia.

An unidentified species of *Marteilia* was detected for this first time in October 2003 in the epithelium of the digestive tubules in one of 40 Manila clams experimentally deployed in April

2002 to investigate the drastic decrease in commercial *V. philippinarum* stocks in Yamaguchi Prefecture, Japan (Itoh *et al.* 2005). No host reaction such as haemocyte infiltration or necrosis was observed in association with the infection. Because other species of *Marteilia* are known to be pathogenic to their respective hosts, further investigations are required before the impact of this *Marteilia* sp. on Manila clams can be determined. To date, this parasite has not been detected in British Columbia.

A *Marteilioides* like parasite was reported in the oocytes of 1.6% of about 2600 *V philippinarum* from the Hadong and Namhae coasts of southern Kyongnam province, Korea between March 1996 and April 1997 (Lee *et al.* 2001). A similar parasite was also detected in September 2003 in the oocytes of one of 40 clams experimentally deployed from Oita Prefecture to Yamaguchi Prefecture, Japan in April 2002 to investigate the drastic decrease in commercial *V. philippinarum* stocks (Itoh *et al.* 2005). In all cases, infection did not cause any significant host reaction. To date, this parasite has not been detected in British Columbia.

Enzootic Parasites

Rickettsia-like and *Chlamydia*-like prokaryote organisms are common inhabitants of bivalves including Manila clams in British Columbia (Bower *et al.* 1992a, Marshall *et al.* 2003). Microcolonies of these prokaryotes occur in the epithelial cells of the gills and digestive gland. Infections are usually light and have not been associated with disease.

Gregarines in the genus *Nematopsis* are also common inhabitants of bivalves including Manila clams in British Columbia (Bower *et al.* 1992a, Marshall *et al.* 2003). The gymnospores and oocysts (gregarine spores containing a uninucleate vermiform sporozoites), usually occur within a phagocyte that can move within the connective tissue to most organs but are most frequently observed in the gills of its bivalve host. Infection is usually associated with a focal, benign accumulation of a several haemocytes, without significant health effects. Although prevalence can be high, the intensity of infection is usually too low to compromise the health of the clam. Also, multiplication of gregarines is limited in bivalves with completion of the life cycle occurring in the lumen of the intestinal tract of marine arthropods. Another heteroxenous apicomplexan parasite with zoites that have some ultrastructural similarities to merozoites of *Aggregata eberthi* (class Coccidia, suborder Eimerioria) is common in native littleneck clams (*Protothaca staminea*) in British Columbia (Desser and Bower 1997). However this parasite has been rarely observed in Manila clams and only from the northern end of their distribution in British Columbia.

Sphenophrya-like ciliates are pear-shaped ciliates that attached to the gill and palp surfaces during parasitic stages of the life cycle. These ciliates often lack cilia as parasites and have been detected on several species of bivalves including Manila clams in British Columbia (Bower *et al.* 1992a, Marshall *et al.* 2003). The intensity of infection is usually light with little or no evidence of associated pathology.

Trichodina spp. are helmet shaped ciliates that attache to, or locate near the mantle, along the siphon, or gill surface of Manila clams as well as other bivalves in British Columbia. Differences in morphology suggest that more than one species may be involved. However, these ciliates are usually found in low numbers and are apparently innocuous, although prevalence in a clam population can reach 100% (Bower *et al.* 1992a, Marshall *et al.* 2003).

Turbellaria in the order Rhabdocoela and family Graffillidae are frequently detected in the mantle and intestinal tract of Manila clams and other bivalves in British Columbia (Bower *et al.* 1992a, Marshall *et al.* 2003). They seem to pass freely between the mantle cavity and alimentary canal of bivalves with no known affect on their host. Possibly they are midway between being endocommensal and parasitic.

Trematode metacercaria of various species of Digenea have been detected encysted in the tissues of Manila clams and other bivalves in British Columbia. In all cases the prevalence and intensity of infection has been low (Bower *et al.* 1992a, Marshall *et al.* 2003). These parasites are non-reproductive encysted larval stages that must be eaten by the final host (possibly birds or fish) to complete their life cycle. No pathology has been associated with the various species of trematodes (all metacercarial stages) that occur in clams from Canada. However, another trematode that produces sporocycts (asexual reproductive stage) containing many cercaria (identified as *Cercaria tapidis*) were reported from the gonadal tissue of 9.7% of the Manila clams in coastal areas of Korea (Lee *et al.* 2001). This parasite has not been detected in British Columbia.

Mytilicola orientalis is a red coloured elongate parasitic copepod that resides in the intestinal tract of many bivalves in British Columbia including the Manila clam (Bower *et al.* 1992a, Marshall *et al.* 2003). Associated pathology is believed to be negligible or minimal in most cases. However, *M. orientalis* can alter the morphology of the epithelial lining of the gut, and when present in numbers it produces a pea-size swelling of the rectum and has been accused of causing a loss of condition.

Interactions with Native Species

Greatest concentrations of Manila clams are generally found higher in the intertidal zone than where most native species occur. There is some overlap with native littleneck clams, *Protothaca staminea*, although greatest concentrations of this species occur on the middle to lower intertidal zone. There is little to no overlap with butter clams, *Saxidomus giganteus*.

Manila clams are prey for Lewis' moonsnail, *Euspira lewisi*; sunstar, *Pycnopodia helianthoides*; pink star, *Pisaster brevispinis*; and mottled star, *Evasterias trochellii*, although less so than native species that live lower in the intertidal zone (Quayle and Bourne 1972; Harbo 1997). Lambert (2000) reported several species of sea stars that ate bivalve molluscs (*e.g.*, sand star, *Luidia foliata*; rose star, *Crossaster papposus*; rainbow star, *Orthasterias koehleri*), but few venture high enough in the intertidal zone to seriously impact Manila clams. Another potential predator listed by Quayle and Bourne (1972), the ochre star, *Pisaster ochraceus*, is found intertidally but prefers hard substrates where it feeds primarily on mussels, barnacles. limpets and snails. Chew (1989) reported predation of Manila clams by red rock, *Cancer productus*, and graceful crabs, *C. gracilis*, and Toba *et al.* (1992) indicated that Dungeness crab, *C. magister*, and kelp crab, *Pugettia producta*, were potential predators. Small Manila clams were also preyed on by shore crabs, *Hemigrapsus nudus* and *H. oregonensis* in a laboratory setting, but this has not been observed in the field (Bourne and Lee 1973; Toba *et al.* 1992).

Small Manila clams are eaten whole by rock sole, *Lepidopsetta bilineata*; English sole, *Parophrys vetulus*; starry flounder, *Platichthys stellatus*; and pile perch, *Rachochilus vacca*; and siphons of adult Manila clams may be cropped by Pacific staghorn sculpin, *Leptocottus armatus*, which are known to crop *Protothaca* siphons in California (Anderson *et al.* 1982; Peterson and Quammen 1982)

Many ducks utilize a wide range of bivalves in their diets and some may make limited use of Manila clams, including greater scaup, *Aythya marila*; Barrow's and common goldeneye, *Bucephala islandica* and *B. clangula*; and long-tailed duck, *Clangula hyemalis* (Anderson *et al.* 1982; Gibbons and Blogoslawski 1989). However the primary anatid predators on Manila clams are surf scoters, *Melanitta deglandi*, white-winged scoters, *M. fusca* and black scoters, *M. nigra* (Glude 1963; Bourne 1984, 1989; Vermeer and Ydenberg 1989).

Numerous species of migratory shorebirds may make use of Manila clams as prey; in particular dunlin, *Caladris alpina*, which have been documented to utilize other intertidal bivalves (*Macoma*, *Mytilus* and *Protothaca*) in the Strait of Georgia (Verbeek and Butler 1989). They are also eaten by northwestern crow, *Corvus caurinus*, (Richardson 1985; Verbeek and Butler 1989; O'Brien *et al.* 2005) and glaucous-winged gull, *Larus glaucescens*, who remove them from the substrate and drop them on hard surfaces to break the shells (Bourne 1989; Gibbons and Blogoslawski 1989).

Potential mammalian predators include sea otter, *Enhydrus lutra*, and racoon, *Procyon lotor* (Gibbons and Blogoslawski 1989). Humans also affect Manila clam populations through transplants, enhancement, harvest or habitat impacts.

Several species of pea crabs are known to occur in British Columbia (Hart 1982), some of which (*Pinnixia faba*, *Fabia subquadrata*) have been found in the mantle cavity of Manila clams. However the prevalence and intensity of pea crabs in most Manila clam populations is low (Bower *et al.* 1992a, Marshall *et al.* 2003).

PACIFIC OYSTER

Taxonomy

The accepted scientific name is *Crassostrea gigas* (Thunberg, 1793). Coan *et al.* (2000) listed three junior synonyms, one of which was divided into three subspecies (Table 9). Numerous authors have described four regional races or forms of Pacific oysters; Hokkaido, Miyagi, Hiroshima and Kumomoto (*e.g.*, Quayle 1988; Arakawa 1990). Some authors (*e.g.*, Arakawa 1990) believed that the Hiroshima type is a separate species, *C. laperousii*; this species is currently considered a junior synonym of *C. gigas* (Coan *et al.* 2000). The Kumamoto type has been recognized as *C. sikamea*, distinct from *C. gigas* (see below). The Pacific oyster is also known as the Japanese, giant, immigrant or Miyagi oyster (the last a local name related to the race introduced to western North America).

Description

The Pacific oyster is a large oyster, occasionally reaching 30 cm in length (Quayle 1969, 1988; Harry 1985; Pauley *et al.* 1988; Arakawa 1990) (Figure 4). The shells are irregular, largely determined by the substrate the oyster is growing on and degree of crowding. The valves may be smooth or possess highly fluted radial lamellae. The lower cupped left valve is larger than the upper flat right valve. The outside of the valves is white, gray or pale yellow with dark pigment (brown or purple), particularly on the lamellae. The inner surface is white with the adductor muscle scars slightly darker (though not as distinctly darkened as in *C. virginica*).

Distribution

Native Range

The Pacific oyster is naturally found in the western Pacific from Sakhalin Island to Hokkaido, through Honshu to Kyushu. On the continental shore it ranges from Russia through Korea and China into Southeast Asia and Pakistan (Arakawa 1990, Coan *et al.* 2000). In the south, its range overlaps that of two other oysters, the Suminoe oyster, *Crassostrea ariakensis*, and the Kumamoto oyster, *Crassostrea sikamea*.

Introductions

Pacific oysters were introduced to the west coast of North America beginning in 1902 or 1903 in Puget Sound (Galtsoff 1929; Chew 1979; Shatkin *et al.* 1997; Ruesink *et al.* 2005). Subsequent introductions were made throughout Puget Sound, in Grays Harbour and Willapa Bay in Washington; Alsea, Coos, Netarts, Tillamook and Yaquina Bays and the Umpqua River in Oregon; and Humboldt, Morro, Newport, San Francisco and Tomales Bays, Elkhorn Slough, Bodega and Mugu Lagoons, Anaheim Creek and Drakes Estero in California (Chew 1979; Lindsay and Simons 1997; Robinson 1997; Shaw 1997). Pacific oysters were recorded from South Central Alaska (Hines and Ruiz 2001) and have been introduced as far west as Kachemak Bay (Foster 1991, 1997), but have not reproduced successfully in Alaska (Foster 2001; Ruesink *et al.* 2005). Oysters were reported to have become established in western Mexico after they were introduced from the western USA and were reported as established in Pearl Harbour, Oahu, Hawaii by Ruesink *et al.* (2005), although Coles *et al.* (1999) did not find them. However, Hunter *et al.* (1995) reported on contaminants found in *Crassostrea gigas* from Kaneohe Bay, Oahu, Hawaii; oysters from five sites in the bay were "pried from the substratum with stainless-steel diving knives" suggesting that they were naturally set rather than spread for culture purposes. Coles *et al.* (2002) indicated that *C. gigas* had been introduced to Kaneohe Bay since 1939, and was still established there.

In British Columbia, Pacific oysters were first introduced to Ladysmith Harbour and Fanny Bay in 1912 or 1913 (Quayle 1969, 1988; Bourne 1997). These small-scale introductions were unregulated; it is likely that government agencies were unaware of the introductions (Bourne 1979). Small-scale introductions likely continued and large-scale importation of seed oysters began in 1925. Evidence of successful reproduction was first seen in Ladysmith Harbour in 1925, 1926 and 1932, followed by successful reproduction and spread of Pacific oysters to areas beyond Ladysmith Harbour in 1936 (Elsey 1932, 1934; Elsey and Quayle 1939; Quayle 1964, 1969, 1988; Bourne 1979). Pacific oysters were transplanted to other growing areas in the Strait of Georgia and widespread reproductive success was reported in 1942, 1958 and 1961 which resulted in establishment of Pacific oyster populations throughout the strait. Pacific oysters were transplanted to Esperanza Inlet and Barkley, Clayoquot and Kyuquot Sounds on the west coast of Vancouver Island in 1937; these resulted in some expansion of populations in Barkley Sound and only limited local reproductive success in the other areas[2] (Bourne 1979). Oysters were transplanted to various areas of the North Coast of BC, including five sites evaluated for raft culture in 1967 and 1968 (Quayle 1971), without successful reproduction (Bourne 1979). Sloan *et al.* (2001) and Gillespie (2007) reported records of Pacific oysters in Haida Gwaii but found no evidence of successful reproduction[3].

There are currently 432 tenures licensed to culture Pacific oysters in BC (Table 10). Most of these (343) are in STZ 4 and there are 120 in PFMA 14. Most of the remaining tenures (86) are on the west coast of Vancouver Island (STZ 5). Records of ITC transfer permits show that 770 introductions were made from 1982-2005 (Table 11). As with Manila clams, most introductions were to the Strait of Georgia (STZ 4, 610 permits) and the west coast of Vancouver Island (STZ 5, 87 permits).

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[2] Relatively few areas support productive populations of "wild" Pacific oysters; the Provincial government only accepts proposals for fisheries for four areas of the coast: Strait of Georgia (five sites), Jervis Inlet (10 sites), Desolation Sound (14 sites), and West Coast Vancouver Island (five sites in Nootka Sound and two sites in Barkley Sound)(S. Pilcher, BC Ministry of Agriculture and Lands, pers. comm.).

[3] While this paper was in revision, DFO surveys confirmed public reports of successful reproduction of Pacific oysters in Skidegate Inlet, Haida Gwaii, and discovered natural-set Pacific oysters in Tasu Sound on the west coast of Haida Gwaii (Gillespie, unpublished data).

At least two areas in British Columbia provide a steady supply of seed from regular natural reproduction (Bourne 1979). Pendrell and Hotham Sounds in the Strait of Georgia have been used by industry as seed collection sites since the 1940s (Quayle 1969), and Quayle (1988) reported that Pipestem Inlet in Barkley Sound and Tlupana Inlet in Nootka Sound began to show potential for commercial seed sets in the 1980s. Similarly, Dabob and Quilcene Bays in Hood Canal and southern Willapa Bay are natural seed areas in Washington State (Chew 1979).

Ruesink *et al.* (2005) collated data on introductions of *C. gigas*, indicating that 69 countries had imported *C. gigas*, 14 had documented established populations, three were judged likely to become established, 16 were unlikely to become established, nine were not established, one indicated some disagreement as to whether establishment had occurred and 26 were unclassified (Table 12). Pacific oysters are now established on all major coasts in the northern hemisphere with the exception of the Atlantic coast of North America (Shatkin *et al.* 1997).

In the southern hemisphere, Pacific oysters were introduced to Australia in the 1940s, 1950s and in 1970 and established populations in New South Wales and Tasmania (Bourne 1979). Pacific oysters are legally defined as a noxious fish in New South Wales where they are a nuisance to the established fishery for Sidney rock oysters, *Saccostrea commercialis*. Pacific oysters have also become established in New Zealand alongside native *S. commercialis*, although the culture industry prefers *C. gigas*. There has been some concern as Pacific oysters have been found in commercially valuable beds of green mussels, *Perna canalicula*. Pacific oysters were introduced to South Africa in 1950 and became established in 2001 (Ruesink *et al.* 2005). They were introduced into Fiji, New Caledonia, New Hebrides, Palau, Tahiti and Tonga, but have not become established (Bourne 1979). In South America they have been introduced to Chile, Peru, Brazil and Argentina. In Argentina, Pacific oysters were introduced through an unregulated attempt to begin a culture facility, which was subsequently abandoned (Orensanz *et al.* 2002; Escapa *et al.* 2004). They have become established and are expanding along the coast around Bahia San Blas, and experimental transplants continue in other areas of the country. Pacific oysters are part of a suite of exotic species (barnacle, polychaete, mussel, oyster, macroalgae and cordgrass) that are having profound ecological effects on the Argentinean coast (Orensanz *et al.* 2002).

Streftaris *et al.* (2005) indicated that Pacific oysters had been introduced to all the major seas of Europe (Arctic, Atlantic, Baltic, Black, Mediterranean and North), but did not specifically indicate where naturalized populations had become established. *C. gigas* has become established in Belgium, Denmark, France, Germany, Italy, the Netherlands, Portugal and Spain; introductions to the Black Sea and Norway did not result in established populations (Shatkin *et al.* 1997; Ambrogi 1998; Gomoiu *et al.* 1998; Goulletquer *et al.* 1998; Hopkins 1998; Nehring 1998; Wolff and Reise 1998; Ruesink *et al.* 2005). Galil and Zenetos (1998) documented introductions of *C. gigas* to Tunisia, the Ionian Sea, Greece and Cyprus with the general comment that populations had been established outside shellfish farms. There is some disagreement as to whether Pacific oysters have become established in the United Kingdom (Walne and Helm 1979; Ruesink *et al.* 2005).

Early importations of Pacific oysters to France were coincident with outbreaks of two viral diseases that essentially eliminated the Portuguese oyster, *Crassostrea angulata*, from France (Shatkin *et al.* 1997). The French government initially banned further imports and then imported more Pacific oysters to support an oyster industry on the West Coast, but these introductions resulted in outbreaks of two haplosporideans in the native oyster, *Ostrea edulis*, and establishment of several exotic species, including barnacles and macroalgae (Maurin and LeDantec 1979; Shatkin *et al.* 1997). Further imports were banned in 1982, but Pacific oysters were successful enough to support the industry through natural reproduction, spreading throughout the former range of *C. angulatus* and into Arcachon, Brittany and Southern Normandy.

Pacific oysters were imported to the Netherlands in the 1960s after extreme weather destroyed most endemic European flat oyster stocks (Shatkin *et al.* 1997). They were initially contained in the Oosterschelde, but have been found in the Westerschelde and Lake Grevelingen. They have been particularly successful in the Wadden Sea, where they are forming large reefs and causing concern regarding the exclusion of native mussels, *Mytilus edulis* (Diederich 2005a,b; Diederich *et al.* 2005; Nehls *et al.* 2006).

Habitat Preferences

Pacific oyster populations in BC generally occur relatively high in the intertidal zone on hard substrates (Bourne 1979, Ruesink *et al.* 2005). A preferred settlement substrate is oyster shell and large aggregations form if populations are not disturbed. Under appropriate conditions they can form reefs on gravel banks at the mouth of small streams, *e.g.*, Lucky Creek in Barkley Sound.

Physiological Tolerances

Pacific oysters grow at temperatures between 3-35°C (optimal 11-34°C) and salinities of 10-30‰ (optimal 20-30‰)(Mann *et al.* 1991). They can survive air temperatures of -4C when exposed by the tide (Quayle 1969). Filtration rate, and therefore the amount of food collected, varies with temperature to a maximum at approximately 20°C. Similarly, Pacific oysters respond to changes in salinity by altering the gape of the shells to the point where filtration rate is reduced below approximately 20‰ (Pauley *et al.* 1988). Temperatures of 16-34°C (optimal 20-25°C) and salinities of 10-42‰ (optimal 35‰) are required for spawning.

Oyster larvae require sustained temperatures of 18°C or above and salinities of 19‰ for at least two weeks for successful metamorphosis (Mann *et al.* 1991; Shatkin *et al.* 1997), although some authors describe longer time requirements; *e.g.*, 20°C or greater for at least three weeks (Pauley *et al.* 1988). Lower temperatures may allow complete development but increase the time larvae are vulnerable to predation as plankton. Larvae can survive only for short periods at temperatures below 15°C and above 30°C (Pauley *et al.* 1988).

Reproductive Biology

Pacific oysters are protandric hermaphrodites (Quayle 1969, 1988; Pauley *et al.* 1988). All oysters spawn as males in their first reproductive season, but may change sex thereafter; sex change occurs in the winter. Quayle (1988) reported a general belief that environmental conditions affected sex ratios with females changing to males when and where food supply was poor, and males changing to females when food supply is good. He cited cases where populations in productive areas had a preponderance of females in older age classes, while less productive areas had more males in older age classes.

Sexual maturity is reached in the first year of life (Pauley *et al.* 1988). Gonadal development and spawning are dependent on salinity to some extent, but primarily on temperature (see Physiological Tolerances above). In BC, gonadal development commences as temperatures begin to rise in March (Table 13). Gonads are fully developed by June and spawning may occur from June to September, most commonly in July and August. Successful spawning at certain sites where temperatures are sufficient (*e.g.*, Pendrell Sound) occurs in most years, with widespread spawning less common.

Fecundity has been estimated at 50-100 million eggs per market size (76 mm TL) female (Quayle 1969).

Early Life History

Pacific oyster larvae develop quickly after fertilization and reach the veliger stage in 28 hours (at 22°C) to 72 hours (at 14°C) (Pauley *et al.* 1988). They continue to develop through D-hinge and umbo stages and develop eye spots just prior to settlement. Time to settlement is dependent on temperature, and Quayle (1969, 1988) reported pelagic larval periods ranging between <20 days at 22°C and 30 days at 19°C in Pendrell Sound.

When larvae are fully developed and a suitable substrate is found the larvae attach the left shell to the substrate with cement produced by a gland in the foot. The larvae then metamorphose, losing the eyespot, velum, foot and anterior adductor muscle and develop the gill and mantle for adult life.

Growth and Lifespan

It is difficult to assess growth in oysters because growth rates are affected by tidal height, temperature, substrate and aggregation, and because age cannot be determined from shells as in most clam species (Quayle 1969, 1988). Oysters attached to hard surfaces tend to follow the contours of the surface as they grow. Those grown in soft mud or arranged in dense clusters tend to be narrow and elongated, while those grown on hard gravel tend to be round and deep, often with extensive fluting on the shell. Most information on growth is from oysters of known age (*i.e.*, whose date of settlement is known).

Pacific oysters planted in Ladysmith Harbour grew from 5 mm TL to 109 mm TL between April 1952 and June 1955 (Quayle 1969). Growth was variable between different lots of seed. Growth varies seasonally with greatest growth between April-May and October, associated with temperatures greater than 10°C.

In general, Pacific oyster growth is relatively rapid in young oysters and decreases with age; Pacific oysters in BC generally have reduced growth rates after 4-5 years of age (Quayle 1969, 1988). Maximum age was reported as 40 years with longer life attained at more northern latitudes (Pauley *et al.* 1988).

Migratory Behaviour

Pacific oysters can only disperse through pelagic larval stages. Once suitable habitat for settlement has been selected, adults are entirely sessile.

Elsey (1934) and Quayle (1969, 1988) documented larval dispersal from reproductive events in 1932 and 1936 in Ladysmith Harbour, location of the only oyster stocks in the area that could have produced the larvae. The 1932 spawning produced settled larvae primarily in the harbour with a few individuals found 11 km to the south and 14 km to the east (Elsey 1934). The 1936 spawning resulted in settlement of larvae at False Narrows, approximately 32 km to the north and Saanich Inlet 56 km to the south (Quayle 1969, 1988).

Food Preferences

As sessile, obligate filter feeders, oyster diets are limited to what is carried to them in the water column (Quayle 1969, 1988). Common food items are bacteria, protozoans, diatoms, invertebrate larvae and inanimate organic "detritus". The relative importance of diatoms and organic detritus (with associated bacteria) is uncertain.

Pathogens and Parasites

Exotic Pathogens

Oyster velar virus disease is caused by an icosahedral DNA virus thought to be an irido-like virus but affiliations with the morphologically similar viruses that cause gill disease in *Crassostrea angulata* and haemocyte infection virus disease (HIV) are unknown. This disease was diagnosed in Pacific oyster larvae from two shellfish hatcheries in Washington State, USA. However, this pathogen is believed to be widespread including virtually all temperate waters of the world where Pacific oysters are found (Elston 1979, 1980, 1993). Viral infection of the velar epithelium, can cause severe hatchery losses (nearly 100%) in affected tanks. The disease usually appears in March to May, but may also occur throughout the summer. The effect of subclinical exposure to this disease on subsequent remote settings of the larvae and grow-out of the seed is not known. Reports by the industry of the occurrence of this disease in British Columbia have not been confirmed.

A herpes-type virus disease from *Crassostrea gigas* in France has been described as Ostreid Herpes Virus type 1 (OsHV-1). However, the apparent lack of host specificity and loss of several gene functions in OsHV-1 prompts speculation that this virus may have resulted from interspecies transmission in the context of the introduction and intensive culture of non-native bivalve species (Arzul *et al.* 2001a, 2001b; Renault *et al.* 2001b; ICES 2004). It is not known if the herpes-like viruses reported from various species of oysters and other bivalves from other locations in Europe, the east coast of the United States, New Zealand and Australia are the same or different species of virus from that studied in France. In France, the disease spreads quickly and was associated with high mortalities (80 - 100%) among *C. gigas* and *O. edulis* larvae and spat in commercial hatcheries (Renault *et al.* 1995, 2000). Pathology may be related to poor husbandry such as elevated temperatures and crowding and is most prevalent during the summer periods. To date, there has been no indication of impacts at the stock level in Europe. This disease has not been detected in British Columbia. *Marteilioides chungmuensis* is a protozoan parasite that infects the oocytes of *C. gigas* in Korea and Japan. This parasite can affect large areas of the reproductive follicles causing irregular enlargement of the infected gonadal tissues. Histological observations suggested that *M. chungmuensis* invades immature ova which move to the center of the follicle and growth of the parasite was highly correlated with growth and maturation of host gonadal cells (Itoh *et al.* 2002). Infected eggs may be liberated via the genital canal or retained in the ovarian follicle and this parasite can have a significant effect on the reproductive output of an infected female oyster. Infection can also cause spawning failure by delaying spawning and destroying ripe oyster oocytes (Ngo *et al.* 2003). Infection also significantly reduced glycogen levels and serum protein concentrations affecting metabolic recovery after spawning (Park *et al.* 2003). Infected oysters lose their marketability due to the unappetising appearance and thus can cause a serious economical impact. This parasite has not been detected in British Columbia.

Exotic Parasites and Minor Diseases

Perkinsus marinus is a protozoa that has severely impacted *Crassostrea virginica* populations in the Gulf of Mexico and the east coast of the United States. Although *C. gigas* has been experimentally infected with this parasite, this species of oyster seems to be more resistant to the disease than *C. virginica* (Meyers *et al.* 1991). This parasite has not been detected in British Columbia.

Marteilia refringens is a protozoan parasite that severely impacted *Ostrea edulis* and mussels (*Mytilus* spp.) populations in the coastal waters of Atlantic Europe from southern United Kingdom to Portugal. Initial stages of infection (without spore formation) were reported in the epithelium of the apical part of the stomach of *C. gigas* from Brittany, France (Cahour 1979) and Galicia, Spain (Montes *et al.* 1998). Montes *et al.* (1998) proposed that *Marteilia* sp. infections in *C. gigas* were transitory and not an obstacle for the culture of the Pacific oyster in areas enzootic for *M. refringens*. This parasite has not been detected in British Columbia.

Haplosporidium nelsoni is a protozoan parasite commonly called MSX (Multinucleate Sphere X) disease that has severely impacted *C. virginica* populations in north-eastern USA and recently in the Bras d'Or Lakes, Nova Scotia. This parasite has also been reported from *C. gigas* in California, Washington, France, Korea and Japan (Friedman *et al.* 1991a, Friedman 1996). Effects of *H. nelsoni* on *C. gigas* have not been described but some authors speculate that it may be pathogenic, especially for juvenile oysters. However, haplosporidiosis has not been associated with mortality of *C.gigas* (Elston 1999). This parasite has not been detected in British Columbia.

Undescribed protozoans which may be species of Microspora were reported from *C. gigas* in Humboldt Bay, California; Korea; and south western Japan including Hiroshima Bay. Matsusato and Masumura (1981) speculated that the parasite in *C. gigas* from Japan may belong to the Subclass Coccidiida. All infections occur in the cytoplasm of mature oyster ova. Occasionally surrounding tissue exhibits a marked haemocyte infiltration response and some parasitized eggs are necrotic. Infection appears to be seasonal, corresponding to the gonadal cycle of the oyster, but the reservoir of infection during the nonproliferative gonadal phase of the oyster is unknown. Also enigmatic is the mechanism by which the oyster becomes infected. Vertical transmission (from one generation to the next via the ova) is suspected but not yet proven. This parasite has not been detected in British Columbia.

Invasive ciliates of juvenile *C. gigas* have not yet been identified to species. However, they are believed to belong in the family Orchitophryidae of the order Scuticociliatida which includes species that are facultative or obligate parasites and histophagous such as the species isolated from sea stars. These ciliate infections have been reported from western USA and New South Wales, Australia where they are considered to be opportunistic invaders. When invasive, they can cause morbidity and mortality in juvenile (seed) oysters less than about 3 mm in shell height with the disease most common in oysters with shell heights of 0.5 to 1.5 mm. Cumulative mortalities in affected cultures of oyster seed usually exceed 50%, and the infection was considered as serious although sporadic for nursery production of the early seed stage in Washington state, USA (Elston *et al.* 1999a). Apparently normal cultures of oyster seed can degenerate to heavily infected terminal cultures in 1 to 2 days. However, subclinical infections occur for several days before the dramatic culture failure ensues (Elston 1999). This parasite has not been detected in British Columbia.

Digestive tract impaction of larval *C. gigas* has been reported in oyster hatcheries in the state of Washington, USA and Tasmania, Australia. The identity of the protozoa involved is not know but was suggested to be a *Dermocystidium*-like organism or possibly a *Hyalochlorella* colourless alga or a phycomycete. Affected oyster larvae, especially larvae between 140-150 µm in height, had reduced mobility and mortality rates exceeding 90%. Larvae which completed metamorphosis within 12 days appeared to survive infection better than slower growing larvae.

Apparently identical spheres have also been observed in the gut of juvenile oysters (spat), older oysters and other molluscs with no associated mortality. In British Columbia, this disease has not been detected in oyster larvae but similar structures are occasionally observed in the gut of mature bivalves.

Echinocephalus crassostreai is a nematode parasite of *C. gigas* found in oyster populations on the coast of Hong Kong and adjacent coast of The People's Republic of China (Cheng 1978). The second- and third-stage larvae of *E. crassostreai* occur primarily encysted in the gonad of *C. gigas* with minimal associated pathology. However, this nematode may cause gastric or other types of granulomatous lesions in humans if accidentally ingested live. This parasite has not been observed in British Columbia.

Several species of pea crabs occur in the mantle cavity of various bivalves in British Columbia, but none have been reported from *C. gigas* in BC (Hart 1982). However, *Pinnnotheres pholadis* has been reported from *C. gigas* in Japan (Cheng 1967). Although these crabs feed on food items collected by their hosts and their presence may reduce market value, no evidence of direct pathology has been reported.

The etiology of haemocytic neoplasia in oysters is unknown. In diseased oysters, the gradual appearance of neoplastic haemocytes occurs throughout the soft tissues with associated disruption of normal function of the haemocytes. The neoplastic haemocytes progressively replace normal haemocytes and eventually the overwhelming numbers of these abnormal cells impede physiological processes resulting in death of affected oysters. Although this disease has been reported in *C. gigas* from various locations (Peters 1988, Elston *et al.* 1992), this disease has not been detected in oysters on the west coast of Canada. However, a similar condition of unknown cause is prevalent in mussels in this area (Bower 1989).

Viral gametocytic hypertrophy causes massive hypertrophy of individual gametes and gametogenic epithelium by replicating in the host nucleus. Host response to infection is negligible and the level of infection is generally low with no indication of associated mortality. Although this disease has been reported in *C. gigas* from the west coast of the U.S., Korea and Japan (Elston 1997), this disease has not been detected in oysters on the west coast of Canada.

Enzootic Pathogens

Nocardia crassostreae is an Actinomycete bacterium that causes a disease currently called nocardiosis but has also been known as fatal inflammatory bacteraemia (FIB), focal necrosis, multiple abscesses, summer mortality and Pacific oyster nocardiosis (PON) (Friedman *et al.* 1998). Nocardiosis has been reported in association with high mortalities in *C. gigas* on the west coast of North America from British Columbia to California, and in Japan (especially in Matsushima Bay) (Imai *et al.* 1968, Friedman *et al.* 1991b). In British Columbia, nocardiosis has only been detected in oysters from the Strait of Georgia and associated inlets. Although infected oysters have been detected throughout the year, associated mortalities usually occur during the late summer and fall. In BC, the extent of associated mortalities has not been accurately measured but estimated at about 35% in some localities.

Mikrocytos mackini (Denman Island disease) is an intracellular protistan parasite of *C. gigas* that is infectious to all other species of oysters tested to date including *Ostrea conchaphila*, *Crassostrea virginica* and *Ostrea edulis* (Bower *et al.* 1997). Focal intracellular infection of vesicular connective tissue cells result in haemocyte infiltration and tissue necrosis which produces visible green pustules that affect marketability. Severe infections and mortalities are most evident in older oysters (over 2 years) and occur predominantly in April and May after a 3-

4 month period when temperatures are less than 10 °C (Bower 2005). Approximately 10% of infected *C. gigas* appear to recover. This parasite has been detected in oysters throughout the Strait of Georgia and confined to other specific localities around Vancouver Island, and from adjacent areas of the State of Washington, USA. In Washington, mortalities due to infection have not been detected.

Enzootic Parasites

Ostracoblabe implexa is a fungus that invades the shell where it induces the production of severe warts on the internal surface of the shell (usually adjacent to the adductor muscle) in several species of oysters from around the world including *C. gigas* in British Columbia. If the area beneath the adductor muscle is infected, attachment is weakened and closing of the shell is compromised due to excessive shell production in that area. Distortion can render the oyster unmarketable. Proliferation of the fungus is restricted to waters where temperatures exceed 22 °C for more than two weeks, thus shallow beds are more severely affected than deep growing sites. In BC, the prevalence of infection is usually low (less than 1%).

Gymnophallid metacercariae (larval trematodes) of the species *Gymnophalloides tokiensis* infect 2-year-old *C. gigas* in some areas of Japan with prevalence approaching 100% and mean intensities of 402 metacercaria per oyster. Heavily infected oysters had higher water content, reduced levels of glycogen, protein and fat, poor growth, general debilitation, and reduced survival. The Gymnophallid metacercaria detected in *C. gigas* from British Columbia occur at low prevalence and intensity and are thought to be innocuous. Neither the primary nor the definitive host is known for Gymnophallidae of oysters and the species that occurs in BC has not been identified.

Mytilicola orientalis is an elongate red coloured parasitic copepod that resides in the intestinal tract of bivalves including *C. gigas*. This parasite is believed to have been introduced from Japan with seed oysters and is now widely spread along the west coast of North America, including British Columbia (Bernard 1969). Associated pathology is believed to be negligible or minimal in most cases (Steele and Mulcahy 2001). However, *M. orientalis* can alter the morphology of the epithelial lining of the gut with no apparent affect on the health of its host.

Various species of parasitic copepods attached to gills of oysters have been reported from around the world. The vast majority of species are innocuous due to the low prevalence and intensity of infection, despite the fact that most species are strongly attached to the gills. However, *Myicola ostreae* causes gill lesions in *C. gigas* and *C. angulata* in France and *Ostrincola* sp. has caused severe gill erosion in a remnant introduced population of *C. virginica* in British Columbia.

Rickettsia-like and *Chlamydia*-like prokaryote organisms are common inhabitants of bivalves including oysters in British Columbia. Microcolonies of these prokaryotes occur in the epithelial cells of the gills and digestive gland. Infections are usually light and have not been associated with disease in BC. A *Chlamydia*-like organism was associated with visible gill lesions and occasional mortalities in *C. gigas* from the Atlantic French coast in 1992-1993 (Renault and Cochennec 1995).

Larval and juvenile vibriosis consisting of systemic infections of various species of *Vibrio* and other naturally occurring, ubiquitous bacteria has been encountered during the larval culture and seed production of various bivalves including oysters. In these cases, systemic infection of the soft-tissues of the larvae and juveniles results in tissue necrosis (due to production of exotoxin by the bacteria) and death. In juvenile oysters, the bacteria that cause chronic abscess disease can be sequestered by new shell deposits and the infection resolved. However, the condition can cause mortalities (when the mantle is breached leading to overwhelming bacteremia) and significant loss of growth in intensively cultured juvenile oysters have been reported (Elston 1999, Elston *et al.* 1999b). In general, vibriosis appears to be directly related to poor husbandry and can be prevented by appropriate hatchery techniques.

Cytophaga-like bacteria colonize and breakdown the hinge ligament of bivalves including *C. gigas* (Dungan *et al.* 1989). Any bivalve species or size may be infected but the greatest impact is on individuals smaller than 1 cm shell height. This disease is particularly severe when growth of juvenile bivalves is retarded for various reasons. Loss of the hinge ligament caused by these bacteria can impede normal respiration and feeding and perforation of the ligament allows access of secondary infectious agents to the soft tissues. Although ubiquitous in the marine environment, this bacterium is usually not a problem for health and growing bivalves which are capable of replacing the hinge ligament eroded by *Cytophaga* colonisation.

Gregarines in the genus *Nematopsis* are common inhabitants of bivalves including oysters in British Columbia. The gymnospores and oocysts (gregarine spores containing a uninucleate vermiform sporozoites), usually occur within a phagocyte that can move within the connective tissue to most organs but are most frequently observed in the gills of its bivalve host. Multiplication of gregarines is limited in bivalves with completion of the life cycle occurring in the lumen of the intestinal tract of marine arthropods such as crabs. In bivalves, the infection is usually associated with a focal, benign inflammatory response, without significant health effects.

Hexamita are protozoan flagellates which are cosmopolitan inhabitants of oysters including *C. gigas* in British Columbia. These organisms are commonly found in low intensity in the intestinal tract of oysters with no associated pathology reported in *C. gigas*. However, associated mortalities, up to 75% over 2 months, were reported in *Ostrea conchaphila* from Puget Sound during periods of cold temperatures (below 12 °C) (Stein *et al.* 1959). Also, poor environmental conditions probably exacerbated the disease in *Ostrea edulis* in recirculating water basins or pits in the Netherlands. In such cases, overwhelming systemic infections occurred.

Stegotricha enterikos is a thigmotrichid ciliate that inhabits the digestive tract of *C. gigas* in British Columbia (Bower and Meyer 1993). Similar ciliates (and possibly the same species of ciliate, often referred to as *Ancistrocoma*-like ciliates) have been reported from the gut of many species of oysters around the world. Although this ciliate lives in the lumen of the digestive gland tubules and may feed on the epithelial cells, no pathology has been directly associated with infection. Prevalence may reach 50% but the intensity of infection is usually low. However, Pauley *et al.* (1967) described a host-defence response and suggested that these ciliates may have an effect under adverse growing conditions for oysters.

Sphenophrya spp. are highly modified ciliates that have been found attached to the gills of many species of bivalve from around the world including *C. gigas* in British Columbia. Although the effects of infections are not well-established, large numbers have been reported with no obvious host-response. However, sphenophyrids in *C. virginica* from the eastern United States were reported to be intracellular where they caused massive hypertrophy of the host cell and its nucleus (Otto *et al.* 1979). To date, no mortalities have been associated with sphenophryiid infections.

Trichodina spp. are helmet shaped ciliates that attach to, or locate near the mantle, labial palps or gill surface of *C. gigas* as well as other bivalves in British Columbia. Differences in morphology suggests that more than one species may be involved. However, these ciliates are usually found in low numbers and are apparently innocuous.

Turbellaria in the order Rhabdocoela and family Graffillidae are frequently detected in the mantle and intestinal tract of *C. gigas* and other bivalves in British Columbia. They seem to pass freely between the mantle cavity and alimentary canal of bivalves with no known affect on their host. Possibly they are midway between being endocommensal and parasitic. In Europe, the turbellaria *Urastoma cyprinae* is reported as an opportunistic mantle inhabitant on the gills of bivalves, or free-living on muddy bottoms. Nevertheless, Robledo *et al.* (1994) reported pathology in the gills of mussels (*Mytilus galloprovincialis*) infested with *U. cyprinae*. In Atlantic Canada, large numbers of *U. cyprinae* can be present in *C. virginica* with no apparent host-response. Under adverse environmental circumstances, however, numbers of *U. cyprinae* may reach levels believed to be detrimental to their hosts (Brun *et al.* 2001). Apparently, *U. cyprinae* is negatively phototactic and is more attracted to *C. virginica* than to other mollusc species such as mussels and clams (Brun *et al.* 1999). It is not known if *U. cyprinae* occurs in British Columbia.

Shell-boring polychaetes (e.g., *Polydora* spp.) are usually innocuous with a low intensity of burrows being confined to the shell of *C. gigas* in British Columbia. However, in southern Brazil; Baja California, Mexico; South Australia and Tasmania, Australia and Marlborough Sounds and Mahurangi Harbour, New Zealand shell-boring polychaetes cause unsightly mud blisters in the shell of *C. gigas*. If the mud blisters comes in contact with the muscle tissue, a yellowish abscess may develop in the adductor muscle. Prevalence and intensity vary considerably with local conditions. Infection rarely causes mortalities and infected oysters can be marketed. However, mud blisters may interfere with shucking and reduce the commercial value of oysters to be served on the half-shell. Mud blisters associated with shell-boring polychaetes have not been observed in British Columbia.

Shell-burrowing clionid sponges (most commonly *Cliona* spp.) penetrate the periostracum forming holes in the outer surface and a tunnel network throughout the shell. The oyster may successfully wall-off the nacreal opening made by the sponge, preventing entry of sand, mud or other irritants. If perforation exceeds shell repair, however, the oyster is weakened and interference with adductor muscle attachment impedes feeding and causes mortality. Sponge tunnels may become inhabited by other organisms, such as polychaete worms, which may reduce market value, but rarely impacts directly on oyster health. Smaller oysters appear less susceptible to shell penetration than thicker shelled individuals.

Interactions with Native Species

Numerous species are associated with oysters by virtue of possessing habitat preferences that match oyster grounds; see Quayle (1969) for a more complete treatment. On the west coast of North America, crabs and sea stars are predators of oysters; the primary species involved are Dungeness crab, red rock crab, graceful crab, sunstar, pink star, ochre star and mottled star (Quayle 1969, 1988; Chew 1979; Pauley *et al.* 1988). These predators are all limited by tolerance of desiccation or salinity, therefore Pacific oysters have some refuge at higher tidal elevations.

Greater scaup (Boune 1989) and black oystercatcher (Butler and Kirbyson 1979; Verbeek and Butler 1989) are predators of Pacific oysters.

Gastropod drills[4] are serious predators of oysters, in particular two introduced species, the Atlantic drill *Urosalpinx cinerea* and the Japanese drill *Ocinebrellus inornatus*[5] (=*Ocinebrina*

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[4] A native species formerly referred to as an oyster drill, the frilled dogwinkle *Nucella lamellosa* (= *Thais lamellosa*), does not prey on oysters, preferring barnacles, clams and mussels (Quayle 1969).

inornata, *Ceratostoma inornatum*, *Ocenebra japonica*, *Tritonalia japonica*). Both these species lack pelagic larval stages and thus have been contained to relatively small areas with larger movements due to human intervention (movement of seed or adult oysters or shell cultch from one area to another).

The Atlantic drill is known from British Columbia (Boundary Bay), Washington (Puget Sound and Willapa Bay) and California (San Francisco, Tomales and Newport Bays); there are numerous records of previously known populations that no longer exist (Carlton 1979). The population at Boundary Bay, British Columbia has not spread (other than a single record at Ladysmith Harbour), has been described as "in decline" since the late 1950s (Carl and Guiget 1958; Quayle 1964) and may no longer exist[6].

The Japanese drill was imported with Pacific oysters, arriving in Puget Sound and southern British Columbia in the 1920s (Carlton 1979). Carlton also listed populations from Willapa Bay, Netarts Bay, Morro Bay and Tomales Bay. British Columbia records include Boundary Bay, Ladysmith and Comox Harbours, Crofton, Thetis Island, Sooke Basin, Holland Bank, Henry Bay and Barkley Sound (Quayle 1964; Griffith 1967; Gillespie, unpublished data).

Feeding behaviour of Japanese drills in laboratory conditions indicated that they prefered *Mytilus* and *Venerupis* to both Olympia and Pacific oysters (Chew and Eisler 1958). However, the oysters used in the experiment were relatively large (32-50 mm), not spat. Quayle (1969, 1988) characterized oyster drills as "among the most damaging of the pests found on oyster beds". The British Columbia Fisheries Act Regulations (Part 3, Clause 8[2]) restricts the movement of "any oysters, oyster seed, oyster cultch, oyster shell, marine organisms adversely affecting oysters or any tools, boats, scows or other material used in connection with oyster culture or harvesting" from Boundary Bay, Crofton, Thetis Island, Ladysmith Harbour, Henry Bay and Comox Harbour to prevent the unintentional transfer of drills to other growing areas.

The flat worm *Pseudostylochus ostreophagus*, also an invasive species that arrived with Pacifc oyster seed from the western Pacific, can be a serious predator on juvenile oysters (Woelke 1957). It was first discovered in Washington State in 1953 and linked to significant mortality of Olympia oysters, and later described as a new species by Hyman (1955). Laboratory trials showed that it could also prey on *C. gigas* and *C. virginica*. *Pseudostylochus* is currently thought to be present in British Columbia, Puget Sound and possibly Willapa Bay (Quayle 1969, 1988; Carlton 1979; Ruiz *et al*. 2000; Wonham and Carlton 2005), including records from Pendrell Sound (Bourne 1978). It is also known from the Atlantic coast of France (Maurin and LeDantec 1979; Streftaris *et al*. 2005).

Two crustaceans on the west coast of North America are considered to be oyster pests; the blue mud shrimp *Upogebia pugettensis* and the bay ghost shrimp *Neotrypaea californiensis* (= *Callianassa californiensis*). These can have impacts on cultured populations of oysters on soft substrate by burial and smothering but do not affect natural populations on hard substrate.

The concept of oysters as ecological engineers has received attention recently (Escapa *et al*. 2004; Ruesink *et al*. 2005). Oyster reefs provide increased habitat complexity, particularly when

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[5] Turgeon *et al*. (1998) documented the change of North American drills from the genus *Ocenebra* to *Ocinebrina*, citing McLean (1996) as the authority for the changes. However, this change applies only to drills native to the Northeastern Pacific. Most authors (*e.g.*, Amano and Vermeij [1998], Ruiz *et al*. [2000], Martel *et al*. [2004a,b,c], Wonham and Carlton [2005]) refer to this species as *Ocinebrellus inornatus*, although this is not universally accepted (see Houart and Sirenko 2003).

[6] Recent information from shell collectors in the Vancouver Shell Club indicate that the Atlantic drill is no longer found in Boundary Bay (Gillespie 2007)

established in large areas of soft substrate. Oyster reefs in Washington support higher diversity of epifauna and higher densities of mussels, scaleworms and tube-building amphipods with little effect on infaunal species, small fish or Dungeness crab (Dumbauld *et al.* 2000; Ruesink *et al.* 2005). However, there is some evidence that increased survival of crabs can increase predation rates on prey such as infaunal clams. In Argentina, oyster reefs supported higher densities of epi- and infaunal species and supported increased foraging by local and migratory shorebird species (Escapa *et al.* 2004). One potential impact is the negative influence of dense aggregations of Pacific oysters on native eelgrass species, whether through direct replacement or downstream effects (Ruesink *et al.* 2005). Little evidence was found for impacts of oysters on hard substrates, where they may increase surface area for epifauna such as barnacles (Bourne 1979; Ruesink *et al.* 2005).

There is assumed to be little competition between Pacific oysters and native Olympia oysters (*Ostrea lurida*) in BC because Pacific oysters occupy higher tidal elevations (Stafford 1913; Bourne 1979; Gillespie 1999; Ruesink *et al.* 2005). It has been commonly noted, however, that introduced oysters often outgrow their native counterparts when their habitat ranges overlap, at least in part because fast-growing species or strains of oyster are specifically chosen for commercial culture (Ruesink *et al.* 2005). Ruesink *et al.* (2005) also proposed that large accumulations of Pacific oyster shell high on the beach represented a recruitment sink for Olympia oyster larvae; in the absence of shell substrate in lower intertidal areas the larvae settle on Pacific oyster shell at elevations not conducive to survival.

JAPANESE SCALLOP

Taxonomy

The currently accepted scientific name is *Mizuhopecten yessoensis* (Jay, 1857) (Table 14). No official common name was designated by Turgeon *et al.* (1998), as the species has not been established in the wild; names from the literature include common scallop, Ezo scallop, giant Ezo scallop, giant scallop, hotate-gai, Japanese common scallop, Japanese scallop, Japanese weathervane scallop, Primorsky scallop, Primorye scallop, Russian scallop, Yesso scallop and Yezo scallop (Brand 2006, Ivin *et al.* 2006; Lauzier and Bourne 2006). The species had previously been placed in the genus *Patinopecten*, but some authors believe that *yessoensis* and *caurinus* not only occupy different genera, but different subfamilies; Fortipectininae for *Mizuhopecten* and Patinopectininae for *Patinopecten* (Motavkin 1986). Some recent literature returns the species to *Patinopecten* and uses *Mizuhopecten* as a subgeneric designation as *Patinopecten* (*Mizuhopecten*) *yessoensis* (*e.g.*, Motoda 1977; Beaumont 2006; Kosaka and Ito 2006). These taxonomic discussions are somewhat contentious in view of the successful hybridization of *M. yessoensis* and *P. caurinus*, albeit in artificial hatchery conditions (Saunders and Heath 1994; Bower *et al.* 1999; Lauzier and Bourne 2006).

Description

The Japanese scallop is superficially similar to the native weathervane, *Patinopecten caurinus* (Figure 5). However, *Patinopecten* has a relatively deep byssal notch, small auricles, flattened ribs and auricular crura with distal denticles, while *Mizuhopecten* has a shallow byssal notch, relatively large auricles, rounded ribs and lacks auricular crura. The shell is large and spheroidal, with the left (upper) valve flattened and a darker brown or brownish-violet colour and the right (lower) valve more convex and white or yellowish-gray. The upper valve can become heavily encrusted with algae, hydroids, barnacles and polychaetes, further camouflaging the scallop on the substrate (Motavkin 1986; Waller 1991; Coan *et al.* 2000). *Mizuhopecten* is amongst the world's largest scallops, achieving shell heights of more than 200 mm (Waller 1991).

Distribution

Native Range

The Japanese scallop is naturally found from the Japan Sea (North Korea, northern Honshu, and Hokkaido) and Pacific coast of Japan from 35°N to the Sea of Okhotsk (61°N), southern Sakhalin Island and southern Kuril Islands (Waller 1991; Coan *et al.* 2000; Ivin *et al.* 2006; Kosaka and Ito 2006). Southern limits on Honshu are Toyama Bay in the Sea of Japan and Tokyo Bay on the Pacific coast (Ventilla 1982; Ito 1991).

Introductions

Japanese scallops were imported under quarantine conditions for a program to develop hatchery, nursery and grow-out technology in British Columbia, beginning in 1983 (Bourne *et al.* 1989; Lauzier and Bourne 2006). The program was transferred to industry in 1989, and development continues. Of particular interest is a shift away from using pure strain Japanese scallops to utilizing a hybrid of *Mizuhopecten yessoensis* and the native *Patinopecten caurinus*, which appears to have heightened immunity to disease and results in decreased mortality rates (Bower *et al.* 1989; Lauzier and Bourne 2006).

There are currently 43 tenures licensed to culture Japanese scallops in BC (Table 15). Most of these (35) are in the Strait of Georgia (STZ 4), with six on the west coast of Vancouver Island and one in each of North Coast (STZ 2) and Haida Gwaii (STZ 1). Records of ITC transfer permits show that Japanese scallops were imported from Japan to hatchery facilities between 1989-1993 (Table 16) and subsequently planted into STZs 1, 2, 4 and 5 after 1997 (Table 17). The number of transfers was small (22 permits) relative to transfer permits for Manila clams or Pacific oysters.

Japanese scallops were introduced for culture (from hatchery stock) in British Columbia, China, Morocco and Japan (Beaumont 2000; Bourne 2000; Minchin 2003; Guo and Luo 2006; Lauzier and Bourne 2006) (Table 18). Attempts at bottom growout in BC were not successful due to predation, and no evidence has been found of natural reproduction and establishment of natural populations (Bourne 2000). However, there is still optimism that scallop culture can develop into a viable industry in British Columbia (Lauzier and Bourne 2006).

Mizuhopecten was introduced to France, with higher rearing success on the Atlantic coast than in the Mediterranean (Barret *et al.* 1996). Japanese scallops also were introduced to Ireland, Scotland and Denmark (Beaumont 2000; Minchin 2003). None of these introductions resulted in established populations (Goulletquer *et al.* 1998; Minchin and Eno 1998) and recent aquaculture activities have concentrated on native scallop species (Norman *et al.* 2006).

Physiological Tolerances

Temperature range for optimal adult survival appears to be 5-23°C (Ventilla 1982; Brand 1991, 2006). Although scallops will continue to grow at temperatures from -2°C to 26°C, optimal growth is seen at 10-15°C in Japan (Kosaka and Ito 2006) or 4-6°C in Russia (Kalashnikov 1991). Significant mortalities were noted when *Mizuhopecten* culture was attempted in southern Japan where spring and summer water temperatures exceeded 22°C (Brand 1991, 2006). Motavkin (1986) indicated that scallop populations were found in areas where winter temperatures did not fall below -1.5°C and summer temperatures did not rise above 18-20°C. Larval temperature tolerance was narrower at 6-20°C with an optimum at 12°C (Motavkin 1986).

In a culture situation in British Columbia, mortality increased drastically to 17-21% when temperatures attained or exceeded 16°C (Cross 1994) and Bourne *et al.* (1989) noted that temperatures above 15°C were stressful to scallops in a culture situation.

Japanese scallops are not generally tolerant of reduced salinity. Ideal salinity is 32-34‰, although at least one population was known to live in salinities of 29-31‰ (Motavkin 1986). Larval salinity tolerance is 30-40‰ with the optimum at 37‰. However, hatchery and culture facilities in British Columbia function well at salinities of 28-30‰ (Bourne *et al.* 1989).

Japanese scallops require well oxygenated water (Bourne *et al.* 1989); a lower limit of 6 ml/l was reported by Motavkin (1986).

Habitat Preferences

Japanese scallops tend to be more abundant in semi-protected bays and gulfs than on open coastlines (Silina and Latypov 2005). *Mizuhopecten* typically occurs in water up to 80 m deep on hard bottom (silted sand, sand or pebbles); they generally avoid soft mud and are not known from rock bottoms. On harder substrates Japanese scallops rest on their right valve on the surface with the ventral margins oriented into any current. They tend to be partially imbedded or buried in softer substrates. Substrate type strongly influences depth and geographic distribution of Japanese scallop populations (Motavkin 1986).

Although reported from 0.5-80 m, highest concentrations are usually between 6-30 m. Immature scallops < 90 mm shell height (SH) tend to be uniformly distributed over the range of depths with suitable substrate. Mature scallops are usually found over a narrower range of depth, which has led to speculation that these concentrations are favourable to successful spawning (Motavkin 1986; Brand 1991).

Reproductive Biology

Japanese scallops are dioescious broadcast spawners. They mature in their second year and begin regular synchronous spawning in their third year (Motoda 1977; Ventilla 1982, Kosaka and Ito 2006). As the gonads mature, the sexes can be distinguished macroscopically; the ovary is pink or orange and the testis is white or cream-coloured. The gonads are in a resting state post-spawning, which corresponds with the season of highest water temperatures, until gametogenesis is initiated in February-March.

Spawning periods were reported to be March-August with geographic variation throughout the Sea of Japan and Okhotsk Sea. Water temperatures recorded during spawning events ranged from 4-12°C. Timing of spawning and critical temperatures can vary geographically; Bourne *et al.* (1989) reported that broodstock from Mutsu Bay, Aomori Prefecture, spawned mid-February to April when temperatures increased to 5-6°C and Ventilla (1982) indicated that spawning commenced in March in Mutsu Bay (when temperatures reached 8°C) but not until mid-May in northern Hokkaido. Motoda (1977) indicated that spawning in Mutsu Bay was complete by mid-May. Kosaka and Ito (2006) indicated a May-June spawning period for in Saroma Lake, north coast of Hokkaido (temperatures of 7-12°C) and Funka Bay, west coast of Hokkaido (temperatures of 4-12°C), April-May for the east coast of Hokkaido and February-June for Mutsu Bay (temperatures of 6-10°C). Lukyanova and Khotimchenko (1994) reported spawning to occur in May in Peter the Great Bay, Russia. Golikov and Scarlato (1970) reported spawning from the end of May until August at temperatures from 8-12°C on the Russian coast of the Sea of Japan. Spawning was delayed until June or July in the Sea of Okhotsk (Motavkin 1986).

Motavkin (1986) described six stages of gonadal development in Japanese scallops in Peter the Great Bay (Table 19). The gonad recovers from spawning in the summer and then is inactive until development commences in October as temperatures decrease. Gonads are completely developed by December or January, and gametogenesis begins in February as temperatures increase from winter lows. Gonads are ripe in April and spawning occurs in May and June. Similar classifications of reproductive stages are available for Hokkaido (Wakui and Obara 1982; Table 20) and Mutsu Bay (Yamamoto 1968; Table 21).

Fecundity estimates for Japanese scallops range from 20-30 million (M) eggs per female (Golikov and Scarlato 1970) to 100-180 M eggs per female (Taguchi 1977; Ventilla 1982; Motavkin 1986; Kalashnikov 1991). Maru (1994) demonstrated that fecundity increased with size and age from approximately 16 M at age 2 to 104 M at age 7. Motoda (1977) commented that effective spawning was considerably less than fecundity, suggesting that a female may release 10-15 M eggs in a season.

Migratory Behaviour

All scallops form a byssus for attachment to substrate when young, some larger species, including *Mizuhopecten*, later become free-living on the substrate and lose the ability to secrete a byssus at larger sizes (Brand 1991). Motavkin (1986) speculated that scallops move about until they find optimal conditions, resulting in narrower ranges of depth in motile adult scallops than in newly settled juveniles. Kalashnikov (1991) noted that high density stimulated swimming activity in settled scallops and that movement was generally diffusive, *i.e.*, resulted in decreased density. Theoretically, movements should balance the need for reducing density (*e.g.*, competition for food, lower environmental quality) with the requirement for proximity to ensure successful fertilization, a balance that may increase patchy distribution based on habitat selection and even generate aggregation in relatively large homogeneous habitats (Orensanz *et al.* 1991).

Although adult scallops are able to swim limited distances, primarily to escape predators, migration of adults is limited. As in other bivalve molluscs with patchy distributions determined by habitat preferences, the primary mode of dispersal, and only opportunity for genetic exchange between metapopulation groups, is through the pelagic larval stage. Larvae may be concentrated in deeper water masses, 4-8 m off bottom (Motavkin 1986). Light may also affect vertical distribution, with larvae migrating towards the surface as light levels decrease at night. Because Japanese scallop larvae spend less time in surface waters, dispersal distances may be less than those shown by oysters and clams, even though larval periods may be similar.

Food Preferences

Scallops are active suspension feeding bivalves utilizing suspended organic material and phytoplankton as food sources (Bricelj and Shumway 1991). Ventilla noted that 80-96% of intestinal contents were detritus or benthic diatoms. Scallops lack siphons, and the ciliary water current that bears food particles enters the mantle cavity along the ventral and anterior edge and exits through a posterior exhalent opening. Scallops tend to orient themselves into the ambient water current such that the exhalent opening is facing away from the direction of flow. Because scallops do not use the gill to sort food particles on the basis of size, they can ingest relatively large food particles; *Mizuhopecten* gut contents have contained particles as large as 950 μm (Bricelj and Shumway 1991).

Growth and Lifespan

The larval period lasts from 22-35 days at 7-13°C, 18 days at 11-13°C, 15 days at 17-19°C, requiring 311-312 degree-days from fertilization to settlement (Motavkin 1986). Eggs were reported to develop to the trochophore stage three days after fertilization at 13°C and four days after fertilization at 8-9°C (Taguchi 1977; Motavkin 1986).

Eggs develop to the early (D-shell) veliger stage in 5-9 days, late veliger/pediveliger stages in 30-35 days and settlement occurs approximately 40 days post-fertilization (Motoda 1977; Kosaka and Ito 2006). Spatfall may be delayed if no suitable substrate is encountered. Naidenko (1994) indicated that, regardless of primary substrate, algal cover was attractive to settling juveniles; they also preferentially settled on *Zostera marina*, hydroids and polychaete tubes. Size at settlement is 230-286 µm (Minchin 2003).

Growth is dependent on temperature, food availability, current velocity and other habitat characteristics (Kalashnikov 1991). Taguchi (1977) indicated suitable temperatures for growth were 6-20°C, with the ideal range being 10-15°C; suitable salinities were 30-40 ppt, with the optimum at 37 ppt. In Russia, *Mizuhopecten* reaches sizes of 45-50 mm SH in one year; size at sexual maturity is 95-110 mm SH, which is achieved at three years of age (Golikov and Scarlato 1970; Kalashnikov 1991). In Japan, scallops reached sizes of 20-50 mm SH in one year, 50-90 mm SH (16-80 g body weight) in two years, 80-120 mm SH (60-170 g) in three years and 100-150 mm SH (110-300 g) in four years; maximum size of 200 mm SH and 1 kg can be reached after 10 years (Ito 1991; Kosaka and Ito 2006).

Growth is relatively rapid in culture situations, with sizes of 60 mm SH achieved in one year and 100 mm SH in two years (Bourne *et al.* 1989; Bourne and Hodgson 1991; Heath and Dobie 2000; Minchin 2003; Lauzier and Bourne 2006). Cross (1994) reported average growth rates between 5-7 mm month^{-1} with deviations of reduced growth from these rates in the summer when temperatures rose above 12.5°C. Growth of hybrid scallops cultured in the Queen Charlotte Islands was relatively rapid from July-December and slow from December-July (Heath and Dobie 2000).

Maximum age for *Mizuhopecten* has been reported as at least 10 years (Golikov and Scarlato 1970; Ventilla 1982; Ito 1991; Kosaka and Ito 2006); perhaps greater than 20 years (Kalshnikov 1991).

Pathogens and Parasites

Exotic Pathogens

Pectenophilus ornatus is a highly modified parasitic copepod with a brood pouch that has been misidentified as a Rhizocephala (Class of parasitic barnacles) (Elston *et al.* 1985). The sac-like female (up to 8 mm in width), brilliant yellowish orange in colour is orally attached to the gill arch of its scallop host and is covered by the scallop's ciliated gill epithelium (Nagasawa *et al.* 1988; Nagasawa and Nagata 1992). The attachment site consists of hypertrophied host tissue that is perfused with host blood upon which the copepod feeds. It is a serious pest that has a negative effect on the scallop's condition (fatness) and reduces market acceptability. It may infect up to 100% of cultured Japanese scallop populations and is present throughout the year with maximum recruitment occurring from spring to summer (Nagasawa *et al.* 1988). This parasite is not known to occur in British Columbia.

Exotic Parasites

Baculovirus-like particles have been reported in one epithelial cell of the digestive gland of a clinically healthy Japanese scallop from Abashiri waters of Hokkaido, Japan. The virus-like particles were observed during a study on the relationship of histological structures in digestive diverticula to nutrient accumulation. The significance of this observation is not known (Chang *et al.* 2002).

Trichodina pectenis and *Trichodina* sp. have been reported within the mantle cavity of Japanese scallops from Gulf of Peter the Great (Sea of Japan). Prevalence varied from 20-100% with no directly associated pathology. However, they may play a role as secondary parasites since they often appeared in very large numbers on the body of weakened scallops (Kurochkin *et al.* 1986). Although not yet detected in scallops in British Columbia, *Trichodina* sp. have been reported in other bivalves in the province and thus are expected to also occur in scallops. No pathology associated with infection has been reported from molluscs in British Columbia.

Enzootic Pathogens

An unidentified intracellular prokaryote has been associated with pinkish-orange pustules up to 10 mm in diameter in the soft tissues and possibly lack of growth (appearing like erosion) and concholin deposition in patches along the edge of the shell (Bower *et al.* 1992b). Laboratory studies indicate that the aetiological agent infects the haemocytes and pathology is inversely dose dependant. Scallops (7-12 cm in shell height) inoculated intramuscularly with high concentrations of lesion homogenates from diseased scallops usually die with overwhelming infections 2-4 weeks after injection. These acute infections are often complicated by secondary septicemia. Injections of low concentrations resulted in a 2 month prepatent period and presence of pinkish-orange pustules up to 10 mm in diameter in the adductor muscle. Lesions observed histologically resembled those observed in scallops from six grow-out localities that experienced poor growth and high mortalities in 1989 (Bower and Meyer 1994). This disease appears to be associated with stress induced by inappropriate scallop culture practices.

Perkinsus qugwadi is a protozoa that is pathogenic to Japanese scallops in British Columbia and did not seem to infect native scallops (*Chlamys rubida* and *Chlamys hastata*) (Bower *et al.* 1992b; Blackbourn *et al.* 1998; Bower *et al.* 1998, 1999). In the Japanese scallop, massive proliferation of *P. qugwadi* throughout the connective tissue of all organs overwhelmed the scallop and resulted in death. Many infected scallops had creamy-white pustules up to 5 mm in diameter on all organs but most frequently on the gonad, digestive gland and mantle. Interestingly, the extent of haemocytic response did not necessarily correspond to the level of infection. This disease can cause high mortality in juvenile scallops (often exceeding 90%) but appears to be somewhat less infective to adult Japanese scallops which usually have a lower prevalence of mortality (about 50%). However, *P. qugwadi* was not readily transmitted between scallops except by a low percentage (less than 15%) of heavily infected juvenile scallops (less than 40 mm shell height) in which the zoospores developed. Progeny of Japanese scallops that survived an epizootic outbreak of *P. qugwadi* had a significant increase in resistance to infection and resulting mortalities. Hybrid scallops, resulting from a cross between *P. yessoensis* females (from the same group of scallops that survived an epizootic outbreak of *P. qugwadi*) and *Patinopecten caurinus* males (native to British Columbia), had similar resistance to *P. qugwadi* (Bower *et al.* 1999). The identification of scallop stocks that are resistant to *P. qugwadi* has facilitated the development of a scallop culture industry in British Columbia and this parasite has not been encountered since the late 1990s.

Enzootic Parasites

Rickettsia-like and *Chlamydia*-like prokaryote organisms are common inhabitants of bivalves including scallops in British Columbia. Microcolonies of these prokaryotes occur in the epithelial cells of the gills and digestive gland. Infections are usually light and have not associated with disease. Heavy infections have been observed in Japanese scallop spat raised in salt water ponds in British Columbia. However, no apparent disease was associated with the infections and the heavy infections were quickly lost from spat that had been placed into an open-water grow-out system.

Larval vibriosis consisting of systemic infections of various species of *Vibrio* and other naturally occurring, ubiquitous bacteria has been encountered during the larval culture of various bivalves including scallops. In these cases, systemic infection of the soft-tissues of the larvae results in tissue necrosis (due to production of exotoxin by the bacteria) and death. However, vibriosis appears to be directly related to poor husbandry and can be prevented by appropriate hatchery techniques.

Gregarines in the genus *Nematopsis* are also common inhabitants of bivalves including scallops in British Columbia. The gymnospores and oocysts (gregarine spores containing a uninucleate vermiform sporozoites), usually occur within a phagocyte that can move within the connective tissue to most organs but are most frequently observed in the gills of its bivalve host. Infection is usually associated with a focal, benign inflammatory response, without significant health effects. Multiplication of gregarines is limited in bivalves with the completion of the life cycle occurring in the lumen of the intestinal tract of marine arthropods.

Shell-boring polychaetes (*Polydora* spp.) are usually innocuous with a low intensity of burrows being confined to the shell. However, in British Columbia, stunting, abnormally thickened shells and high mortalities caused by high intensities (burrows too numerous and interwoven to count in shells of dead scallops) of *P. websteri* have precluded culture of introduced *P. yessoensis* in a few localities (Bower 1990, Bower and Meyer 1994). In Japan, Mori *et al.* (1985) suggested that *Polydora* may have an adverse affect on growth of Japanese scallops in some areas. Also, thickening of the shell (3-4 fold) by the scallop to prevent the polychaete from penetrating through the shell to living tissue may reduce swimming capacity of the scallop, thereby making it more accessible to predators (*i.e.*, sea stars).

Shell-burrowing clionid sponges (most commonly *Cliona* spp.) penetrate the periostracum forming holes in the outer surface and a tunnel network throughout the shell. Scallops may successfully wall off any openings that penetrate through the inner nacre to the soft tissues. If perforation interferes with adductor muscle attachment, impaired feeding can cause mortalities. Sponge tunnels may become inhabited by other organisms, such as polychaete worms, and chronic soft-tissue irritation may result in secondary bacterial or fungal infections. Scallop responses to such damage are energetically costly and chronic perforation can cause significant weakening and death. Also, associated lesions in the soft tissues may become visible in the adductor muscle rendering affected scallops unmarketable. Smaller scallops appear less affected by shell penetration than larger individuals. To date infestations with these sponges has not been a significant problem for the Japanese scallop culture industry.

Interactions with Native Species

There has not been successful outplanting and recovery of large numbers of *Mizuhopecten* in BC (Lauzier and Bourne 2006). Ventilla (1982), Motavkin (1986) and Kalashnikov (1991) discussed native predators in Japan and Russia, primarily the seastars *Asteria amurensis*, *Distolasterias nipon* and *Patiria pectinifera*, but also including the muricid gastropods *Boreotrophon candelabrum* and *Tritonalia japonica* (=*Ocinebrellus inornatus*), Kamchatka crab, *Paralithodes camtshatica*, octopus and benthopelagic fish (primarily flatfish and gobies). He noted that mortality was high in young scallops at high densities, when sea stars would switch to preying on scallops exclusively, but decreased rapidly as density was reduced and scallops grew large enough to have effective escape behaviours. Storms strong enough to have bottom effects at depths where scallops reside can weaken scallops and allow for increased predation by sea stars, smother scallops under substrate or deposit them on beaches as storm debris.

It is likely that predators of *Mizuhopecten* in BC would be similar to those of the native *Patinopecten*. While these are not well known, Bourne (1991) reported predation of young *Patinopecten* by flatfishes in BC, and indicated that seastars such as *Pycnopodia helianthoides* and *Evasterias troschellii* were potential predators known to occur on scallop beds. Predation by a non-indigenous flatworm, *Pseudostylochus ostreophagus*, was implicated as a contributing factor in high mortality of small Japanese scallops in the Strait of Georgia and culture techniques were adapted to reduce this mortality (Bourne 2000; Lauzier and Bourne 2006). *Octopus dofleini* are known to capture small scallops (*Chlamys hastata*) in BC (Gillespie *et al.* 1998b), and could be a potential predator on small *Mizuhopecten*. Bourne listed several species of crabs, including *Cancer gracilis*, *C. magister* and *C. productus* as potential predators of scallops, although the term was used in a generic sense that included other species than weathervanes.

As stated above, there has been documented development of viable hybrids from crosses of female *Mizuhopecten yessoensis* and male *Patinopecten caurinus* in a hatchery setting in BC (Saunders and Heath 1994; Bower *et al.* 1999). These hybrids apparently have higher resistance to disease, particularly *Perkinsus qugwadi*, than pure-strain Japanese scallops (Lauzier and Bourne 2006).

Saunders and Heath (1994) commented that there appeared to be different optimal spawning times for the two species, but these differences may also have been due to the relatively greater age of the native scallop broodstock. Whether such hybridization could occur in natural settings has not been investigated, but the potential for losing native genotypes through hybridization with non-indigenous species is a serious concern in discussions of the effects and dynamics of non-indigenous species (*e.g.*, Grosholz 2002).

DISCUSSION

The three species considered in this review fall into two categories based on their specific biological characteristics. Both Manila clams and Pacific oysters are intertidal, have established populations in portions of BC and are limited in their distribution by minimum temperature thresholds for successful reproduction and recruitment. Japanese scallops are subtidal and are not yet known to be established in BC although they do not appear to have temperature-related limitations on reproduction and/or recruitment.

TEMPERATURE

Sea temperature is the primary factor determining the distribution of marine organisms, although local extremes of salinity and availability of suitable habitat can affect population abundance on a local level (Seed 1976). Temperature affects mortality rates of adults and larvae, successful development of gonads, spawning behaviour, and metamorphosis from pelagic larvae to sessile adults. For successful spawning, Manila clams and Pacific oysters require that minimum temperature thresholds of 14°C and 16°C be exceeded, respectively.

We examined mean monthly sea surface temperatures at lighthouse stations in each of the STZs (Table 22 and Table 23). Temperature profiles for STZ 1 (Haida Gwaii, Figure 6), STZ 2 (North Coast, Figure 7) show that these temperatures are rarely achieved and they never occur for any period of time in STZ 3 (Johnstone Strait, Figure 8). In contrast, mean temperatures exceed 14°C in June through September in STZ 4 (Strait of Georgia, Figure 9) with the exception of Cape Mudge in May and September and Active Pass in May. Mean monthly temperatures exceed the 16°C threshold in July and August with the exception of Cape Mudge. In STZ 5 (West Coast Vancouver Island, Figure 10) mean monthly temperatures exceed the 14°C threshold only at Nootka Point in July through September, with June very close at 13.9°C (Table 23).

These temperatures represent conditions at lighthouses in open waters. Conditions are different in extensive inlet and passage systems on the West Coast of Vancouver Island and in the southern portion of the North Coast and temperatures are higher than in open waters. However, temperature data at lighthouse stations correlate well with the distribution of Manila clams and Pacific oysters in BC. Manila clams have established populations in the southern portion of STZ 2 and throughout STZ 4 and 5. Temperatures in the northern portion of STZ 2 and all of STZ 1 and 3 have not been conducive to successful reproduction. Similarly, Pacific oysters only recruit sporadically in STZ 4 and 5 as temperatures in STZ 1 through 3 have been too low to allow successful reproduction and settlement.

These temperature data are less meaningful when discussing potential reproductive success of Japanese scallops as they are sensitive to rapid fluctuations in temperature to induce spawning. Sea surface temperatures in all STZs represent less of a range than temperatures in the species' native range. Also, there may be little correlation of sea surface temperatures to temperatures in depths at which the scallops reside. However, we note that temperatures in all STZs increase from lows in January through March and remain in the range considered to be optimal for spawning for Japanese scallops (5-12°C).

HYBRIDIZATION

Manila clams and Pacific oysters do not hybridize with native bivalves in BC. However. *Mizuhopecten* and *Patinopecten* are morphologically, biologically and ecologically very similar, both falling into Minchin's (2003) ecomorph D. By definition, similar ecomorphs are expected to use similar habitats and have overlapping or coinciding ranges. Therefore, if *Mizuhopecten* was to become established in BC, it would likely co-habit the same habitat as *Patinopecten*, greatly increasing the potential for hybridization.

In addition to habitat preferences, Minchin (2003) indicated that duration and season of spawning were important considerations when determining potential for hybridization between introduced and native species of scallops. Spawning period of native weathervane scallops in the Gulf Islands of BC is April to mid-June (MacDonald and Bourne 1987; Bourne *et al.* 1989; Lauzier and Bourne 2006). Spawning time of the MacIntyre Bay population may be later; Alaskan populations are reported to spawn from May to early July (Barnhart 2003). *Mizuhopecten* spawns from April to August (with variation from location to location) in its native range (Golikov and Scarlato 1970; Motavkin 1986; Osada *et al.* 2004). Therefore, it is possible that the two species may spawn in synchrony if they are placed in close proximity.

The effects of temperature on timing on development and potential spawning of cultured scallops in BC may be quite different from those of the parent stock in Japan as the scallops used in culture are viable hybrids of Japanese and native weathervanes and these hybrids are raised in oceanographic conditions different from those in Japan and Russia. More information is required on the relation of temperature to gonadal development in *Mizuhopecten-Patinopecten* hybrids used in culture to assess whether they could reproduce naturally and hybridize with native weathervanes in BC.

Minchin's final concern, that of the biological potential for hybridization assessed through karyotype and allele similarity studies, has already been rendered redundant by successful production of viable hybrids in BC (Saunders and Heath 1994; Bower *et al.* 1999). The presence of gametes of Japanese scallops in the vicinity of spawning native weathervanes could result in a decrease in reproductive potential as weathervane gametes are wasted on fertilization of potentially suboptimal hybrids.

Relatively few areas of BC are known to harbour significant populations of weathervane scallops; primarily the southern Gulf Islands in the Strait of Georgia and Dixon Entrance off the Queen Charlotte Islands with some known collection sites off the west coast of Vancouver Island (Bourne 1969, 1991; Bourne *et al.* 1989; Lauzier and Bourne 2006). Assurances that hybridization could not occur because of timing of spawning or separation of stocks through suspension culture are specious, as the biological characteristics of the hybrids in BC waters have not been presented in the literature and equipment failures result in deposition of scallops on the bottom (Heath and Dobie 2000). It would be prudent to avoid placing cultures sites for *Mizuhopecten* in close proximity to known *Patinopecten* beds, as documented and advocated by Heath and Dobie (2000), until more is known about the potential for hybridization in nature.

An important distinction not well related in the literature is that the hybrids are viable not only in terms of development, growth and survival, but are reproductively viable as well (W. Heath, BC MAL, pers. comm.).

SHELLFISH TRANSFER ZONES

Shellfish Transfer Zones were initially developed using disease information in conjunction with generalized water body geography and PFMA boundaries but their development did not include other biological parameters (ITC 2004). Examination of the distributions of the three species considered here provide insight on how appropriate these zones are when considering future introductions of the three species examined.

The STZs as currently defined mesh well with biological characteristics of Pacific oysters. *C. gigas* was introduced into STZ 4 and eventually transplanted to STZ 5. Activities of the aquaculture (especially importation of oyster larvae and seed from remote facilities) have maintained substantial populations of this oyster in both of these zones. Because of oceanographic conditions in each zone, particularly related to critical minimum temperature thresholds for reproduction and recruitment, oysters have not dispersed outside of these zones; water temperatures are insufficient in STZ 1-3 to allow establishment of populations[7]. These biological parameters coincide with the current Shellfish Transfer Zones for Pacific oysters which divides BC into two zones (STZ 4-5 and STZ 1-3)

Manila clams were also introduced into STZ 4 and transferred to STZ 5, in both cases accidentally with Pacific oysters. Temperature thresholds are lower for Manila clams than for Pacific oysters, however, and *V. philippinarum* has naturally dispersed beyond the borders of STZs 4 and 5. Few populations exist in Johnstone and Queen Charlotte Straits (STZ 3) as temperatures here are low enough to limit successful recruitment. Manila clams have naturally dispersed into the southern portion of STZ 2, and in fact are sufficiently abundant and prolific to support commercial fisheries in PFMA 7. They have not become established in northern inlets or in Burke and Dean Channels because water temperatures are low due to year-round input of glacial water as are the open ocean conditions in Queen Charlotte Sound. However, the channels and passages near Waglisla afford warmer temperatures than glacially-influenced inlets and have been colonized by Manila clams. When considering dispersal of Manila clams, STZ 2 is not a natural unit because southern areas support Manila clam populations while northern areas do not. These biological parameters do not coincide with the current Shellfish Transfer Zones for Manila clams which considers BC to be one zone for this species.

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[7] While this is generally true, there may be microhabitats, *e.g.*, head of long inlets or lagoons, or instances of unusually warm temperatures that would allow successful reproduction in STZs 1-3. This is demonstrated by successful recruitment of Pacific oysters in Skidegate Inlet and Tasu Sound, Haida Gwaii (STZ 1)(Gillespie, unpublished data).

The discussion is moot in the case of Japanese scallops, which have not become established in BC to date. However, information gathered here suggests that temperature would not limit dispersal of *M. yessoensis* should establishment occur.

FUTURE WORK

Information collected, synthesized and reviewed in this paper provides a model for biological synopses in support of risk assessments for the ITC. Future work should move forward on two pathways.

The biological synopses presented in this paper should be used as models for evaluation of the risk assessment process defined in the National Code (DFO 2003). Such an exercise would evaluate the model synopses and reveal any previously-undetected information gaps in the synopses. As well, the results of the risk assessments would inform us of additional information that would be beneficial in future synopses prepared for new species assessments.

Biological synopses should be completed for indigenous species of interest to the aquaculture industry as well as other exotic species currently licenced in BC. Priority of each species can be determined through consultation with the ITC and FAM. Indigenous species which appear to be of relatively high priority for aquaculture include Pacific geoduck clams (*Panopea abrupta*), Nuttall cockle (*Clinocardium nuttallii*), northern abalone (*Haliotis kamtschatkana*), red and green sea urchins (*Strongylocentrotus franciscanus* and *S. droebachiensis*, respectively) and giant Pacific sea cucumber (*Parastichopus californicus*). Five exotic species that are currently licensed for culture in BC but lack reviewed biological synopses are European flat oyster, Eastern oyster, Kumamoto oyster, Atlantic blue mussel and Mediterranean mussel.

RECOMMENDATIONS

1. **Information gathered in this paper should be used as models and subjected to risk analyses as described in the National Code.** Such an exercise would allow evaluation of the information present, information gaps identified, and the requirements for a complete biological synopsis that could provide guidance for future risk assessments of exotic or indigenous species.
2. **Similar information should be gathered for high priority indigenous species currently of interest to the aquaculture industry and for remaining exotic species licensed for culture in BC.** Industry has expressed interest in pursuing culture of several indigenous species, and some research (*e.g.*, hatchery seed production) is ongoing in support of these interests. Similarly, there are five species currently licensed for culture in BC that do not have reviewed biological synopses on file to inform transfer decisions required from the ITC. Specific priorities for these species should be determined through consultation between all parties involved.

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Table 1. Description of Shellfish Transfer Zones (STZs) in British Columbia (adapted from ITC 2004).

STZ	Name	Description
1	Haida Gwaii	Contiguous waters surrounding Haida Gwaii within Pacific Fisheries Management Areas (PFMA) 1, 2, 101, 102 and 142.
2	North & Central Coast	Contiguous waters of the mainland coast within PFMA 3 to 10 inclusive, PFMA 103 to 107 inclusive and PFMA 109 and 110.
3	Queen Charlotte Strait	Contiguous waters of Queen Charlotte and northern Johnstone Straits within PFMA 11, 12 and 111.
4	Georgia Strait	Contiguous waters of southern Johnstone, Georgia and Juan de Fuca Straits within PFMA 13 to 18 inclusive, PFMA 19-4 to 19-12 inclusive, and PFMA 28 and 29.
5	West Coast Vancouver Island	Contiguous waters of the west coast of Vancouver Island within PFMA 20 to 27 inclusive, PFMA 121 to 127 inclusive and PFMA 19-1 to 19-3 inclusive.

Table 2. Summary of information required for Risk Assessment under the National Code on Introductions and Transfers of Aquatic Organisms (DFO 2003) for Manila clams.

Taxonomy

Scientific Name:

Venerupis (*Ruditapes*) *philippinarum* (A. Adams and Reeve, 1850)

Synonyms:

Venus philippinarum A. Adams and Reeve, 1850: 79;
V. tessellata A. Adams and Reeve, 1850: 79 (first reviser: Tomlin 1923);
Tapes indica G.B. Sowerby II, 1852: 694;
T. denticulata G.B. Sowerby II, 1852: 694;
T. biradiata Deshayes, 1853: 170;
T. grata Deshayes, 1853: 170;
T. quadriradiata Deshayes, 1853: 171;
T. japonica Deshayes, 1853: 181;
T. violascens Deshayes, 1853: 181;
T. semidecussata Reeve, 1864: plate 13 *ex* Deshayes MS;
T. ducalis Römer, 1870: 9;
T. philippinarum okupi Bryan, 1919: 125;
Paphia bifurcata Quayle, 1938: 139.

Common Name(s):

Manila clam, **Japanese littleneck**, asari, Pacific palourde, ribbed carpet shell, steamer clam, Japanese cockle, Filipino venus, short-neck clam, Japanese carpet shell, Pacific carpet clam

Higher Taxonomy:

Mollusca; Bivalvia; Heterodonta; Veneroida; Veneroidea; Veneridae.

Description

Medium sized venerid clam, oval in outline, radial and concentric sculpture, lunule flat or concave, variable color on outside of valves from uniform grey or brown to red and black radial rays, inside of valves yellow or white with purple stain at posterior end, lacks crenulations on inner ventral margin, siphon tips split.

Table 2. continued.

Distribution

Native

Sakhalin Island and Kuril Islands, southwestern Russia and northern Japan through Korea to China and Hong Kong.

Introductions

Central and southern British Columbia from Laredo Inlet (51°59'N) to Puget Sound, Grays Harbour and Willapa Bay, Washington, and from Humboldt Bay to Elkhorn Slough in California. Also Tahiti, US Virgin Islands, Hawaii, U.K., France, Spain, Italy, Germany Belgium, Israel and Tunisia. Established populations in western North America, Hawaii, England, France and Italy.

Habitat Preferences

Intertidal, from approximately 1 m above MLLW to the upper third of the intertidal zone. Protected beaches, preferring gravel, sand and mud.

Physical Tolerances

Salinity

Eggs, larvae and newly settled juveniles require 25-35‰, adults tolerant of reduced salinity for short periods. Mortality noted at salinities ≤10‰.

Temperature

Water temperatures greater than 21°C for extended periods can increase mortality in adults, especially post-spawning. Gonad activation commences at temperatures >8°C, maturation requires 12°C and spawning requires 14-20°C. Egg and larval development optimal from 18-26°C. Winter kills occur when exposed to freezing temperatures and prevailing winds during low tides.

Reproductive Biology

Dioescious, broadcast spawner. One extended spawning period in south and central BC, June-November. Successful recruitment sporadic. Fecundity high (1.5-11.7 million eggs/female).

Growth Rate and Lifespan

Growth rapid through 4-5 years, slower at greater ages. Individual growth variable dependent on substrate and tidal height. In BC, reach legal size (38 mm TL) in 3.5-5.0 years. Maximum age in BC approximately 14 years.

Migratory Behaviour

Dispersal only through pelagic larval stages. Pelagic larval stage approximately three weeks in BC.

Food Preferences

Obligate filter feeder ingesting plankton and suspended organic matter from the water column.

Table 2. continued.

Pathogens and Parasites

(* indicates detection in British Columbia)

Exotic pathogens

- Herpes-like virus infection
- *Vibrio tapetis* (cause of brown ring disease)
- *Perkinsus olseni*

Exotic parasites

- unidentified haplosporidia
- *Marteilia* sp.
- *Marteilioides* sp.

Enzootic pathogens

- none known

Enzootic parasites

- *Rickettsia*-like and *Chlamydia*-like organisms*
- Gregarines*
- *Sphenophrya*-like ciliates*
- *Trichodina* spp.*
- Turbellaria*
- Trematode metacercaria*
- *Mytilicola orientalis**
- Pea crabs*

Interactions with Native Species

Little evidence of competition with *Protothaca* and *Saxidomus* as Manilas inhabit broader areas of the intertidal zone and extend higher into the intertidal than native species. No evidence of hybridization with native species. Act as prey for many native invertebrates, fish, birds and mammals.

Table 3. BC shellfish tenures licensed for culture of Manila clams, Venerupis philippinarum, *by Pacific Fisheries Management Area (PFMA) and Shellfish Transfer Zone (STZ).*

PFMA - Subarea	STZ	No. of Tenures	Total by PFMA	Total by STZ
4-12	2	1	1	1
10-05	3	2	2	2
13-12	4	6		
13-13	4	4		
13-15	4	26		
13-16	4	12		
13-17	4	6	54	
14-03	4	3		
14-05	4	1		
14-07	4	4		
14-08	4	73		
14-09	4	2		
14-10	4	2		
14-11	4	3		
14-14	4	1		
14-15	4	12	101	
15-03	4	3		
15-04	4	19		
15-05	4	10	32	
16-02	4	1		
16-04	4	1		
16-08	4	1		
16-10	4	1		
16-12	4	1		
16-13	4	1		
16-19	4	11	17	
17-02	4	3		
17-05	4	4		
17-06	4	2		
17-07	4	6		
17-08	4	2		
17-09	4	2		
17-16	4	3		
17-17	4	3		
17-20	4	4	29	
18-07	4	1	1	234
20-06	5	2		
20-07	5	7	9	

Table 3. continued.

PFMA - Subarea	STZ	No. of Tenures	Total by PFMA	Total by STZ
23-03	5	2		
23-04	5	6		
23-06	5	9		
23-08	5	2		
23-09	5	1		
23-10	5	1	21	
24-10	5	2	2	
25-03	5	1		
25-04	5	1		
25-06	5	3		
25-08	5	2		
25-11	5	3		
25-13	5	2	12	
26-03	5	1		
26-08	5	1		
27-11	5	1	3	47
Grand Total		284	284	284

Source: ITC database.

Notes: Sites licensed for culture of Manila clams do not necessarily have the species on-site, nor is ITC approval for transfers to the site automatic. See Table 1 and Figure 1 for definitions of STZs and Figure 2 for PFMAs.

Table 4. Number of requests for import licences (hatchery introductions) of Manila clams, Venerupis philippinarum, *by year and destination zone, in British Columbia, 1982-2005.*

Source hatcheries are located in BC, US Pacific Northwest States and Hawaii. Land-based destinations indicate that stock was not seeded directly into the wild.

	Destination (STZ)					
Year	2	4	5	Unknown	Land-based	Total
1982		1	1			2
1984		1	1	1		3
1985			1			1
1986				1		1
1987		1	2			3
1988		3				3
1989		5	1			6
1990		9	2	1		12
1991		9	2		1	12
1992		22	1			23
1993		12	3	3		18
1994		13	1	1		15
1995		5	2	1		8
1996		14	5	4		23
1997		13	3	6		22
1998		21	1	2		24
1999	1	29	3	1	1	35
2000	2	35	4			41
2001	5	29	1	1		36
2002	2	26	1			29
2003		27	1		1	29
2004	1	21			1	23
2005	1	26			3	30
Total	12	322	36	22	7	399

Table 5. Results of DFO exploratory intertidal surveys for Manila clams, Venerupis philippinarum, *in British Columbia, 1990-2004.*

PFMA	Year	Location	Incidence	A	S	P	M	H	Source
1	1997	Massett Inlet	0/8	8	-	-	-	-	4
1	1997	Naden Harbour	0/4	4	-	-	-	-	4
3	2002	Nasoga Gulf	0/2	2	-	-	-	-	10
3	2002	Observatory Inlet	0/6	6	-	-	-	-	10
3	2002	Winter Inlet	0/2	2	-	-	-	-	10
3	2003	Nasoga Gulf	0/1	1	-	-	-	-	10
3	2003	Observatory Inlet	0/6	6	-	-	-	-	10
3	2003	Portland Canal	0/2	2	-	-	-	-	10
3	2003	Portland Inlet	0/3	3	-	-	-	-	10
3	2003	Winter Inlet	0/1	1	-	-	-	-	10
4	1997	Lucy Islets	0/4	4	-	-	-	-	4
5	1990	Kitkatla Inlet	0/4	4	-	-	-	-	1
5	1998	Anger Anchorage / Cosine Island	0/4	4	-	-	-	-	6
6	1990	Campania Island	0/6	6	-	-	-	-	1
6	1990	Kitasu Bay / Meyers Passage	2/6	4	1	1	-	-	1
6	1994	Aristazabal Island	5/11	6	2	3	-	-	5
6	1994	Higgins Passage	6/8	2	-	3	3	-	5
6	1994	Laredo Inlet	4/4	-	1	3	-	-	5
6	1998	Aristazabal Island	1/8	7	-	1	-	-	6
6	1998	Chapple Inlet / Surf Inlet	0/7	7	-	-	-	-	6
6	1998	Meyers Passage / Laredo Inlet	2/5	3	-	1	1	-	6
6	2000	Laredo Inlet	2/3	1	-	1	1	-	7
6	2000	Princess Royal Channel	0/7	7	-	-	-	-	7
6	2004	Tolmie Channel	0/5	5	-	-	-	-	9
7	1990	Gunboat Passage	7/9	2	-	5	2	-	1
7	1990	Lama Passage / Hunter Channel	5/9	4	-	2	2	1	1
7	1990	Mathieson Channel	5/7	2	-	4	1	-	1
7	1990	Seaforth Channel / Joassa Channel	5/5	-	-	1	2	2	1
7	1990	Seaforth Channel / Raymond Passage	6/7	1	-	1	-	5	1
7	1990	St. John Harbour	4/8	4	2	1	-	1	1
7	1991	Gale Passage	6/7	1	-	-	2	4	2
7	1991	Spider Anchorage	5/8	3	1	-	3	1	2
7	1991	Spiller Channel / Return Channel	5/5	-	-	1	1	3	2
7	1991	Stryker Island	4/5	1	-	1	1	2	2
7	1991	Thompson Bay	3/3	1	-	-	-	2	2
7	1994	Lama Passage / Gunboat Passage	3/3	-	-	-	-	3	5
7	1994	Spiller Channel / Bullock Channel	8/10	2	-	3	-	5	5
7	1994	Troup Passage	4/4	-	-	-	-	4	5
7	1996	Gale Passage	2/2	-	-	-	1	1	5
7	1996	Joassa Channel / Louise Channel	4/5	1	-	-	1	3	5
7	1996	Kakushdish Harbour	4/4		-	2	1	1	5
7	1996	Return Channel / Troup Passage	10/10	2	4	1	1	2	5
7	1998	Finlayson Channel	1/5	3	1	1	-	-	6
7	1998	Sheep Passage / Mathieson Channel	3/6	3	-	3	-	-	6
7	2000	Briggs Inlet	3/5	2	-	1	-	-	7
7	2004	Kildidt Sound	4/5	1	1	3	-	-	9
7	2004	Pt Blackney	3/3	-	-	1	-	2	9
7	2004	Roscoe Inlet	3/3	-	2	1	-		9
7	2004	Spider Anchorage	6/6	-	5	1	-	-	9
8	1991	Kwakshua Channel	3/5	2	-	2	1	-	2
8	1996	Kwakshua Channel	4/8	4	1	3	-	-	5
8	2000	Dean Channel	0/2	2	-	-	-	-	7
8	2000	Fisher Channel	6/6	-	2	3	-	1	7

Table 5. continued.

PFMA	Year	Location	Incidence	A	S	P	M	H	Source
8	2004	Burke Channel	1/4	3	1	-	-	-	9
8	2004	Dean Channel	0/2	2	-	-	-	-	9
8	2004	South Bentinck Arm	0/3	3	-	-	-	-	9
9	1991	Rivers Inlet	0/4	4	-	-	-	-	2
9	1993	Fish Egg Inlet	6/10	4	3	3	-	-	3
9	1993	Rivers Inlet	1/1	-	1	-	-	-	3
9	1996	Safety Cove	0/1	1	-	-	-	-	5
9	2000	Fish Egg Inlet	4/4	-	-	3	-	1	7
9	2004	Rivers Inlet	0/7	7	-	-	-	-	9
10	1993	Smith Sound	6/9	3	-	4	2	-	3
10	2004	Smith Sound	4/4	-	3	-	1	-	9
11	2002	Seymour Inlet / Belize Inlet	3/7	4	2	1	-	-	8
12	1991	Gilford Island	3/6	-	2	1	-	-	2
12	1991	Indian Channel	1/9	8	1	-	-	-	2
12	1993	Blunden Harbour	3/6	-	2	1	-	-	3
12	1993	Deserters Group	0/3	3	-	-	-	-	3
12	1993	Drury Inlet	1/15	15	1	-	-	-	3
12	1993	Nowell Channel / Fife Sound	5/7	2	-	5	-	-	3
12	1993	Pt Harvey	1/6	-	-	1	-	-	3
12	1993	Pt Neville	3/3	-	2	-	1	-	3
12	1994	Pt Elizabeth-Chatham Channel	0/6	6	-	-	-	-	5
12	1996	Pt Harvey	1/3	2	-	1	-	-	5
12	2002	Broughton Strait	0/2	2	-	-	-	-	8
12	2002	Gilford Island	2/4	2	1	1	-	-	8
12	2002	Kingcome Inlet	0/3	3	-	-	-	-	8
12	2004	Broughton Strait	0/1	1	-	-	-	-	9
13	1991	Cameleon Harbour	1/1	-	1	-	-	-	2
13	1991	Kanish Bay	3/3	-	2	-	-	1	2
13	1991	Marina Island	1/1	-	-	-	-	1	2
13	1991	Von Donop Inlet	3/3	-	-	-	1	2	2
13	1992	Drew Harbour	1/1	-	-	-	-	1	3
13	1992	Marina Island	1/1	-	-	-	-	1	3
13	1992	Von Donop Inlet	3/3	-	-	-	-	3	3
13	1993	Nodales Channel	2/5	3	-	2	-	-	3
13	1994	Cameleon Harbour	6/6	-	-	3	2	1	5
13	2000	Cameleon Harbour	1/1	-	-	1	-	-	7
13	2002	Johnstone Strait	3/5	2	-	2	-	1	8
23	2002	Toquart Bay	3/3	-	1	-	-	2	8
24	2000	Clayoquot Sound	6/7	1	-	6	-	-	7
24	2002	Clayoquot Sound	13/14	1	1	6	1	5	8
25	2002	Esperanza Inlet	3/3	-	1	-	2	-	8
26	2002	Kyuquot Sound	6/6	-	1	1	-	4	8
26	2002	Nasparti Inlet	2/2	-	-	-	2	-	8
26	2002	Ououkinsh Inlet	5/7	2	1	2	-	2	8
27	1993	Quatsino Sound	1/18	17	-	1	-	-	3
27	2001	Klaskino Inlet	4/4	-	-	-	-	2	7
27	2001	Klaskish Inlet	3/3	-	1	-	2	-	7
27	2002	Klaskino Inlet	3/3	-	-	2	-	1	8
27	2002	Winter Harbour	2/2	-	-	-	1	1	8

Legend: Incidence = no. of beaches with Manila clams/no. of beaches surveyed; A = Absent; S = Shell only; P = Present (1-30 clams m^{-2}); M = Moderate (31-100 clams m^{-2}); H = High (>100 clams m^{-2}).

Sources: 1-Bourne and Cawdell (1992); 2-Bourne *et al.* (1994); 3-Bourne and Heritage (1997); 4-Gillespie and Bourne (1998); 5-Heritage *et al.* (1998); 6-Gillespie and Bourne (2000); 7-Gillespie *et al.* (2004); 8-Gillespie and Bourne (2005a); 9-Gillespie and Bourne (2005b); 10-Gillespie (unpublished data).

Table 6. Worldwide introductions of Manila clams, Venerupis philippinarum, *with dates of introduction (if available) and indication of establishment.*

Country	Date of Introduction	Established (yes/no, date if known)
Belgium		
Canada (British Columbia)	1930s	1936
France	1972	1988
Germany	1980s	No
Ireland	1982	No
Israel	1987	?
Italy	1982	1980s
Norway	1987	No
Portugal	1980s	
Spain	1980	No
Tahiti	1970s	No
Tunisia	1970s	No
UK (multiple locations)	1980	No
UK (Poole Harbour)	1988	1994
USA (Hawaii)	1880s	1918
USA (West Coast)	1924	1942
US Virgin Islands	1970s	No
Wales	1970s	No

Table 7. Stages of gonadal development of Manila clams, Venerupis philippinarum, *from three regions of British Columbia.*

Number of males (M) and females (F) in each stage and percentage of total sample in each stage (sexes combined).

	Gonadal Stage				
Month	Early Active	Late Active	Ripe	Partially Spent	Spent
North Coast					
May-June 1980	0 M	29 M	0 M	0 M	0 M
	0 F	13 F	4 F	7 F	5 F
	0%	72%	7%	12%	9%
July 1991	0 M	0 M	20 M	0 M	2 M
	0 F	0 F	19 F	5 F	5 F
	0%	0%	76%	10%	14%
July 1993	0 M	0 M	4 M	4 M	1 M
	0 F	0 F	4 F	6 F	2 F
	0%	0%	38%	48%	14%
August 1998	0 M	0 M	15 M	9 M	0 M
	0 F	0 F	14 F	5 F	0 F
	0%	0%	67%	33%	0%
July 2000	0 M	0 M	13 M	9 M	3 M
	0 F	0 F	15 F	6 F	0 F
	0%	0%	61%	33%	7%
Johnstone Strait					
July 1993	0 M	6 M	27 M	6 M	1 M
	0 F	10 F	7 F	6 F	1 F
	0%	25%	53%	19%	3%
July 2000	0 M	0 M	5 M	1 M	0 M
	0 F	0 F	0 F	1 F	4 F
	0%	0%	45%	18%	36%
West Coast Vancouver Island					
July 1993	0 M	1 M	4 M	0 M	0 M
	0 F	0 F	7 F	2 F	0 F
	0%	7%	79%	14%	0%

Source: Bourne 1982; Bourne *et al.* 1994; Bourne and Heritage 1997; Gillespie and Bourne 2000; Gillespie *et al.* 2004.

Table 8. Age of recruitment to legal size (38 mm TL) for Manila clams, Venerupis philippinarum, *from DFO exploratory intertidal surveys in British Columbia, 1990-2004.*

For source references see Table 5.

PFMA	Year	Location	Age at 38 mm TL	Source
6	1994	Aristazabal Island	3.5	5
6	1994	Higgins Passage	3.5	5
6	1990	Kitasu Bay / Meyers Passage	4.5	1
6	1994	Laredo Inlet	4.0-4.5	5
6	2000	Laredo Inlet	3.5-5.5	7
6	1998	Meyers Passage / Laredo Inlet	3.5-4.5	6
7	2000	Briggs Inlet	3.5	7
7	1998	Finlayson Channel	4.0-4.5	6
7	1991	Gale Passage	3.5	2
7	1996	Gale Passage	3.5-4.0	5
7	1996	Joassa Channel / Louise Channel	3.5-4.0	5
7	1996	Kakushdish Harbour	4.0-4.5	5
7	2004	Kildidt Sound	3.5-4.0	9
7	1994	Lama Passage / Gunboat Passage	3.5	5
7	1990	Lama Passage / Hunter Channel	3.5-4.0	1
7	1990	Mathieson Channel	3.5-4.0	1
7	2004	Pt Blackney	4.5	9
7	1996	Return Channel / Troup Passage	3.5-4.5	5
7	2004	Roscoe Inlet	5.5-6.0	9
7	1990	Seaforth Channel / Joassa Channel	3.5-4.0	1
7	1990	Seaforth Channel / Raymond Passage	3.5	1
7	1998	Sheep Passage / Mathieson Channel	4.0-5.0	6
7	1991	Spider Anchorage	3.5	2
7	2004	Spider Anchorage	3.5-4.0	9
7	1994	Spiller Channel / Bullock Channel	3.5	5
7	1991	Spiller Channel / Return Channel	3.5	2
7	1990	St. John Harbour	4.0	1
7	1991	Stryker Island	3.5	2
7	1994	Troup Passage	3.5	5
8	2004	Burke Channel	3.5-4.0	9
8	2000	Fisher Channel	3.5	7
9	1993	Fish Egg Inlet	4.0-4.5	3
9	2000	Fish Egg Inlet	3.0-3.5	7
10	2004	Smith Sound	3.0-3.5	9
11	2002	Seymour Inlet / Belize Inlet	3.0-3.5	8

Table 8. continued.

PFMA	Year	Location	Age at 38 mm TL	Source
12	1993	Blunden Harbour	3.5	3
12	2002	Gilford Island	3.5-4.0	8
12	1993	Nowell Channel / Fife Sound	3.5	3
12	1993	Pt Harvey	4.5-5.0	3
12	1993	Pt Neville	3.5	3
13	1994	Cameleon Harbour	3.5	5
13	1992	Drew Harbour	3.5	3
13	2002	Johnstone Strait	4.5-6.5	8
13	1991	Kanish Bay	4.5	2
13	1993	Nodales Channel	3.5	3
13	1991	Von Donop Inlet	3.5	2
24	2000	Clayoquot Sound	3.5-4.5	7
25	2002	Esperanza Inlet	3.0	8
26	2002	Kyuquot Sound	3.5-4.0	8
26	2002	Nasparti Inlet	3.5-4.0	8
26	2002	Ououkinsh Inlet	4.5-5.5	8
27	2001	Klaskino Inlet	3.5-4.5	7
27	2002	Klaskino Inlet	3.0-3.5	8
27	2001	Klaskish Inlet	3.5-4.0	7
27	1993	Quatsino Sound	4.0-4.5	3
27	2002	Winter Harbour	4.0-4.5	8

Table 9. Summary of information required for Risk Assessment under the National Code on Introductions and Transfers of Aquatic Organisms (DFO 2003) for Pacific oysters.

Taxonomy

Scientific Name:

Crassostrea gigas (Thunberg, 1793)

Synonyms:

Ostrea gigas Thunberg, 1793: 140;
O. laperousii Shrenck, 1861: col. 411;
O. talienwhanensis Crosse, 1862: 149;
O. posjetica Razin, 1934: 36;
Lopha (*Ostreola*) *posjetica beringi* Vialov, 1946: 523;
Lopha (*Ostreola*) *posjetica zawoikoi* Vialov, 1946: 523;
Lopha (*Ostreola*) *posjetica newelskyi* Vialov, 1946: 523.

Common Name(s):

Pacific oyster, Pacific giant oyster

Higher Taxonomy:

Mollusca; Bivalvia; Pteriomorphia; Ostreoida; Ostreidae

Description

Large oyster, shells irregular (shape determined by substrate type), may be smooth or have fluted lamellae. Lower (left) valve cupped, larger than upper (right) flat valve. Valves white, grey or light yellow with brown or purple pigment on lamellae. Inner surface white with darker pigment at adductor muscle scar. Maximum size at least 30 cm TL.

Distribution

Native

Northwestern Pacific from Sakhalin Islands through Hokaido and Honshu to Kyushu, and from Coastal Russia through Korea and China into Southeast Asia and to Pakistan.

Introductions

Currently cultured from Prince William Sound, AK to Newport Bay, CA. Locally established naturally maintained populations from BC to OR, natural sets expected inconsistently in areas that support culture.

Widely introduced worldwide, with established naturally reproducing populations in Autralia, New Zealand, Europe South Africa and Hawaii.

Table 9. continued.

Habitat Preferences

Generally occur in upper intertidal zone on hard substrates. Oyster shell is preferred settlement surface; can form large aggregations or oyster reefs if undisturbed.

Physical Tolerances

Salinity

Adults grow in salinities of 10-30‰ with the optimal range being 20-30‰. Spawning requirement is 10-42‰, optimally 35‰. Larvae require salinities >19‰.

Temperature

Adults grow in 3-35°C, with optimal range of 11-34°C. Spawning requirement is 16-34°C, optimally 20-25°C. Larvae can survive between 15-30°C and require temperatures >18°C for at least two weeks for normal development and settlement.

Reproductive Biology

Protandric hermaphrodite, dioecious broadcast spawner. Age at maturity ca. one year. Spawning regularly successful at limited sites in BC and Washington, occasional widespread spawning success in warm water years. Fecundity high (50-100 million eggs/female).

Growth Rate and Lifespan

Growth rate variable, cannot determine age from shells. Can reach 10 cm TL in three years in BC. Growth initially rapid then decreases after 4-5 years. Maximum age approximately 40 years.

Migratory Behaviour

Adults sessile, dispersal through pelagic larval stages. Larval period up to 30 days in BC, with dispersal of up to 56 km documented.

Food Preferences

Obligate filter feeder, opportunistically utilizing bacteria, protozoans, diatoms, invertebrate larvae and detritus.

Table 9. continued.

Pathogens and Parasites

(* indicates detection in British Columbia)

Exotic pathogens

- Oyster velar virus disease
- Herpes-type virus disease
- *Marteilioides chungmuensis*

Exotic parasites

- *Perkinsus marinus*
- *Marteilia refringens*
- *Haplosporidium nelsoni*
- Microsporidiosis of oyster eggs
- Invasive ciliates of juvenile oysters
- Digestive tract impaction of larval oysters
- *Echinocephalus crassostreai*
- Pea crabs
- Haemocytic neoplasia of oysters
- Viral gametocytic hypertrophy

Enzootic pathogens

- *Nocardia crassostreae**
- *Mikrocytos mackini**

Enzootic parasites

- *Ostracoblabe implexa**
- Gymnophallid metacercariae*
- *Mytilicola orientalis**
- Parasitic copepods attached to gills
- *Rickettsia*-like and *Chlamydia*-like prokaryote organisms*
- Larval and Juvenile Vibriosis*
- *Cytophaga*-like bacteria*
- Gregarines*
- *Hexamita* spp.*
- *Stegotricha enterikos**
- *Sphenophrya*-like ciliates*
- *Trichodina* spp.*
- Turbellaria*
- Shell-boring polychaetes*
- Shell-burrowing sponges*

Interactions with Native Species

Little evidence of direct competition with native oysters, although can have an effect as vectors of disease and through acting as settlement sink for native oysters in suboptimal habitat. Large aggregations serve to increase habitat complexity and support higher densities of epifaunal animals (barnacles, mussels, scaleworms) allowing increased foraging opportunities for migratory birds. Act as prey for native invertebrate, and bird species.

Table 10. BC shellfish aquaculture tenures licensed for culture of Pacific oysters, Crassostrea gigas, *by Pacific Fisheries Management Area (PFMA) and Shellfish Transfer Zone (STZ).*

PFMA - Subarea	STZ	No. of Tenures	Total by PFMA	Total by STZ
2-01	1	1	1	1
4-12	2	1	1	1
10-05	3	1	1	1
13-11	4	1		
13-12	4	8		
13-13	4	6		
13-15	4	34		
13-16	4	17		
13-17	4	12		
13-26	4	2	80	
14-05	4	1		
14-03	4	4		
14-07	4	6		
14-08	4	81		
14-09	4	3		
14-10	4	2		
14-11	4	2		
14-14	4	4		
14-15	4	17	120	
15-03	4	4		
15-04	4	37		
15-05	4	26	67	
16-02	4	1		
16-04	4	1		
16-06	4	5		
16-08	4	2		
16-10	4	5		
16-11	4	5		
16-12	4	4		
16-13	4	2		
16-16	4	3		
16-19	4	10	38	
17-02	4	3		
17-05	4	5		
17-06	4	4		
17-07	4	6		
17-08	4	1		
17-09	4	3		
17-16	4	3		
17-17	4	2		
17-20	4	6	33	

Table 10. continued.

PFMA - Subarea	STZ	No. of Tenures	Total by PFMA	Total by STZ
18-02	4	1		
18-07	4	4	5	343
20-06	5	2		
20-07	5	1	3	
23-03	5	4		
23-04	5	9		
23-05	5	1		
23-06	5	20		
23-08	5	2		
23-09	5	1		
23-10	5	4	41	
24-02	5	1		
24-04	5	1		
24-09	5	8		
24-10	5	2	12	
25-03	5	2		
25-04	5	1		
25-05	5	1		
25-06	5	4		
25-08	5	2		
25-09	5	1		
25-11	5	9		
25-13	5	3	23	
26-02	5	1		
26-03	5	2		
26-08	5	2	5	
27-09	5	1		
27-11	5	1	2	86
Grand Total		432	432	432

Source: BC Ministry of Agriculture and Lands report for February 2006.

Notes: Sites licensed for culture of Pacific oysters do not necessarily have the species on-site, nor is ITC approval for transfers to the site automatic. See Table 1 and Figure 2 for definitions of STZs and Figure 2 for PFMAs.

Table 11. Number of requests for import licences (hatchery introductions) of Pacific oysters, Crassostrea gigas *by year and destination zone, in British Columbia, 1983-2005.*

Source hatcheries are located in BC, US Pacific Northwest States and Hawaii. Land-based destinations indicate that stock was not seeded directly into the wild.

	Destination (STZ)							
Year	1	2	3	4	5	Unknown	Land-based	Total
1983				3				3
1984			4	5				9
1985				14				14
1986			1	24	11			36
1987			1	20	8		1	30
1988				23	4		3	30
1989			1	23	5		4	33
1990				21	5	3	1	30
1991				31	3	3	6	43
1992				37	3	2	2	44
1993		1		29	2	2	2	36
1994				21	1	2		24
1995				14	2		2	18
1996				33	6	2		41
1997			1	32	5	6		44
1998	1	1		40	4	2		48
1999		2		39	4	2		47
2000				44	9	1		54
2001				42	3	4		49
2002	2			42	6			50
2003				31	4	3		38
2004				18	1		2	21
2005	1	1		24	1		1	28
Total	4	5	8	610	87	32	24	770

Source: ITC database.
Notes: See Table 1 and Figure 1 for definitions of STZs.

Table 12. Worldwide introductions of Pacific oysters, Crassostrea gigas, with dates of introduction (if available) and indication of establishment (Ruesink et al. 2005).

Country	Date of Introduction	Established (yes/no, date if known)
Algeria	<1984	
Argentina	1982	1987
Australia (New South Wales)	1967[a]	1985
Australia (Victoria)	1955	Yes
Australia (Western Australia, Tasmania)	1947-1970	Yes
Belgium	1990[a]	Yes
Belize	1980	
Brazil	<1989	Unlikely
Canada (British Columbia)	1912-1977	1925
Channel Islands	<1986	
Chile	1983	
China	1979[b]	
Costa Rica	1979	
Croatia	1980[a]	
Denmark	1980	Yes
Ecuador	1980	No
Fiji	1968-1977	Unlikely
France	1966-1977	1975
French Polynesia	1972-1976	Unlikely
Germany	1971	1991
Greece		
Guam	1975	No
Ireland	<1993	
Israel	1976	Unlikely
Italy	1972	Likely
Japan	1980[b]	
Korean Republic	1980[b]	
Madiera Island	1991	No
Malaysia	1980	
Mauritius	1971	Unlikely
Mexico (East Coast)		
Mexico (West Coast)	1973	Yes
Morocco	<1966	
Myanmar		
Namibia	1990	No
Netherlands	1964-1981	1976

Table 12. (continued).

Country	Date of Introduction	Established (yes/no, date if known)
New Caledonia	1967-1977	Unlikely
New Hebrides	1972-1973	No
New Zealand	1958[a]	Yes
Norway	1985	
Palau	1972-1973	Unlikely
Peru	<1997	
Philippines		
Portugal	1977	Likely
Puerto Rico	1980	No
Russia (Black Sea)	1976	Unlikely
Samoa	1980	
Senegal	<2001	
Serbia and Montenegro		
Seychelles	1974	Unlikely
Singapore	2003	Unlikely
Slovenia		
South Africa	1950	2001
Spain	1980	
Sweden	1980	No
Tahiti	1972-1976	No
Tonga	1975	Unlikely
Tunisia	<1984	
Turkey		Unlikely
UK	1926, 1965-1979	Disagreement
Ukraine	1976	Unlikely
US Virgin Islands	1980	
USA (Alaska)	1980	Unlikely
USA (East Coast)	1930-1990	Unlikely
USA (Gulf Coast)	1930	No
USA (West Coast)	1902	Likely
USA (Hawaii)	1926, 1980	1960? (Pearl Harbour)
Vanuatu	1972	Unlikely
Yugoslavia		

Legend: a = range expansion, b = transplant into native range.

Table 13. Stages of gonadal development of the Pacific oyster, Crassostrea gigas, in British Columbia (Quayle 1988).

Stage	Description	Timing
Inactive	Body appears smooth and even. Reproductive organs replaced with connective tissue with vesicle cells containing fat and glycogen. Gonad undifferentiated as to sex.	November-March
Onset of development		March
Fully developed	Approximately 25% of gonadal area filled with follicles.	April
Gametogenesis	More than 50% of gonadal area filled with follicles.	Late May
Ripe	Gonadal tubules ("spawn veins") visible. Follicles tightly packed with gametes with only thin layer of connective tissue covering gonad.	Late June
Spawning		Late June-September
Spent	Body nearly transparent, gonadal follicles contain only few relict gametes and tissue fragments.	September-October

Table 14. Summary of information required for Risk Assessment under the National Code on Introductions and Transfers of Aquatic Organisms (DFO 2003) for Japanese scallops.

Taxonomy

Scientific Name:

Mizuhopecten yessoensis (Jay, 1857)

Synonyms:

Pecten yessoensis Jay, 1857: 293;
P. brandtii Schrenck, 1861: col. 411; 1867: 484.

Common Name(s):

common scallop, Ezo scallop, giant Ezo scallop, giant scallop, hotate-gai, Japanese weathervane, Japanese scallop, Japanese common scallop, Primorsky scallop, Primorye scallop, Russian scallop, Yesso scallop, Yezo scallop

Higher Taxonomy:

Mollusca; Bivalvia; Pteriomorphia; Ostreoida; Pectinidae

Description

A large scallop (to 200 mm SH), with a flat, dark left (upper) valve and convex, light right (lower) valve. Valves spheroidal, auricles large, byssal notch shallow, ribs rounded, auricular crurae lacking.

Distribution

Native

Sea of Okhotsk, Sakhalin Island, southern Kuril Islands through Russia to North Korea, Hokkaido and northern Honshu, Japan.

Introductions

Northern China, Denmark, France, Ireland, Canada, Morocco. No naturally established populations reported.

Habitat Preferences

Generally found in semi-protected bays and gulfs rather than on open coastlines. Subtidal from 0.5-80 m depth on sand, silted sand or pebble bottoms. Not found in mud or on rocky bottom.

Physical Tolerances

Temperature

Growth occurs from -2-26°C, optimally 4-6°C. Optimal range for adult survival is 5-23°C. Spawning occurs at temperatures of 4-12°C. Larval tolerance 6-20°C with optimum at 12°C.

Salinity

Adults and larvae require high salinity. Adults optimal at 28-34‰, larvae tolerate 28-40‰ with optimum at 37‰.

Table 14. continued.

Reproductive Biology

Dioescious, broadcast spawner. Spawn in spring or summer, depending on water temperatures. Fecundity high; 20-180 millions eggs/female. Larval period 15-35 days dependent on temperature.

Growth Rate and Lifespan

Growth varies with temperature, food availability and other environmental variables. Generally reach 20-50 mm shell height (SH) in one year, 50-90 mm SH in two years, 80-120 mm SH in three years, 100-150 mm SH in four years. Age at maturity is approximately three years (95-110 mm SH). Maximum size (~200 mm SH) requires ten years. Maximum age can be more than 20 years. Growth is faster in culture settings.

Migratory Behaviour

Dispersal through pelagic larval stages. Limited adult movement in response to crowding, predators or seasonal cues (bathymetric migration).

Food Preferences

Active suspension feeders utilizing suspended organic matter and phytoplankton as food sources.

Pathogens and Parasites

(* indicates detection in British Columbia)

Exotic pathogens

- *Pectenophilus ornatus*

Exotic parasites

- Baculovirus-like particles
- *Trichodina* sp.

Enzootic pathogens

- Unidentified intracellular prokaryote*
- *Perkinsus qugwadi**
- Larval vibriosis*

Enzootic parasites

- *Rickettsia*-like and *Chlamydia*-like organisms*
- Gregarines*
- Shell-boring polychaetes*
- Shell-burrowing clionid sponges*

Interactions with Native Species

Potential predators include seastars, flatfishes and octopus. Potential for hybridization with native *Patinopecten caurinus*?

Table 15. BC shellfish tenures licensed for culture of Japanese scallops, Mizuhopecten yessoensis, by Pacific Fisheries Management Area (PFMA) and Shellfish Transfer Zone (STZ).

PFMA - Subarea	STZ	No. of Tenures	Total by PFMA	Total by STZ
2-01	1	1	1	1
10-05	3	1	1	1
13-11	4	3		
13-12	4	2		
13-15	4	4		
13-16	4	1		
13-17	4	2	12	
14-05	4	1		
14-08	4	7		
14-15	4	1	9	
15-04	4	5		
15-05	4	3	8	
16-06	4	1		
16-13	4	1		
16-19	4	2	4	
17-20	4	1	1	
18-07	4	1	1	35
23-04	5	1		
23-06	5	1		
23-10	5	1	3	
24-07	5	2	2	
26-02	5	1	1	6
Grand Total		43	43	43

Source: BC Ministry of Agriculture and Lands report for February 2006.

Notes: Sites licensed for culture of Japanese scallops do not necessarily have the species on-site, nor is ITC approval for transfers to the site automatic. See Table 1 and Figure 1 for definitions of STZs and Figure 2 for PFMAs.

Table 16. Requests for import licences for imports of Japanese scallops, Mizuhopecten yessoensis, to British Columbia, 1989 to 1993.

Year	Transfer	
	From	To
1989	Japan	Quarantine
1991	Japan	Quarantine
1992	Japan	Quarantine
1993	Japan	Quarantine

Source: ITC database.

Notes: Quarantine indicates that scallops were held in approved quarantine with effluent water treatment.

Table 17. Number of requests for transfer licences for Japanese scallops, Mizuhopecten yessoensis, by year and destination Shellfish Transfer Zone (STZ), in British Columbia, 1997-2005.

Transfers are from hatcheries or different STZs within BC. Land-based destinations indicate that stock was not seeded directly into the wild.

	Destination (STZ)						
Year	1	2	4	5	Unknown	Land-based	Total
1997	1						1
1998		1					1
1999			1				1
2000		2	1	2		1	6
2001		1	1	1			3
2003		3					3
2004		1		2	1	1	5
2005		1				1	2
Total	1	9	3	5	1	3	22

Source: ITC database.

Notes: See Table 1 and Figure 1 for definitions of STZs.

Table 18. Worldwide introductions of Japanese scallops, Mizuhopecten yessoensis, with dates of introduction (if available) and indication of establishment.

Country	Date of Introduction	Established (yes/no, date if known)
Canada (British Columbia)	1982, 1992	No
China	1970s	No
Denmark	1985	No
France	1987	No
Ireland	1990-91	No
Japan	1990s	n/a
Morocco	1998	No
Scotland	1980s	No

Table 19. Stages of gonadal development of the Japanese scallop, Mizuhopecten yessoensis, in Peter the Great Bay, Russia (Motavkin 1986, Lukyanova and Khotimchenko 1994).

Stage	Description	Timing
Regeneration	Gonads small, translucent, limp. New acini, gonial cells and connective tissue forming.	June
Inactive	Gonads small, transparent, limp.	Mid-June to September
Onset of development	Gonads larger, developing turgor. Female gonads pale pink.	September to November
Fully developed	Gonads fairly dense, female yellow or pink, male milky white.	December to January
Gametogenesis	Gonads very dense, female yellow, male milky white.	February to March
Ripe	Gonads swollen; occupy most of mantle cavity, female bright orange or pink, male milky white or cream-coloured.	April
Spawning	Gonad very dense and brightly pigmented.	May to June

Table 20. Stages of gonadal development of the Japanese scallop, Mizuhopecten yessoensis, in Lake Saroma, Hokkaido, Japan (Wakui and Obara 1982).

Stage	Description	Timing
Immature	Difficult to distinguish sex. Small number of residual oocytes or spermatozoa may remain.	July-October
Follicular	Gonads sac-like. Oogonia present in ovarian follicles, spermatogonia present and developing in male.	October-March
Growth	Oocytes grow but remain attached to follicular wall, assume pyriform shape. Male follicles contain spermatogonia, primary and secondary spermatocytes and spermoblasts; some may have small numbers of spermatozoa.	November-March
Mature	Pyriform oocytes detach from the follicular wall, become elliptical or polygonal primary oocytes. Male spermoblasts form spermatozoa.	March-June
Spawning	Oocytes and spermatozoa released, vacuoles form in follicles. Few oogonia present and few oocytes remain in female, few spermatozoa remain in male.	May-June

Table 21. Stages of gonadal development of the Japanese scallop, Mizuhopecten yessoensis, in Mutsu Bay, Honshu, Japan (Yamamoto 1968).

Stage	Description	Timing
Resting	Visceral sac shrinks, ovarian vacuole completely empty; difficult to distinguish sex macroscopically.	June-October
Maturing	Oogonia develop and proceed through pyriform phase to become oocytes. Vacuoles of testis fill with spermatogonia, develop to spermatozoa.	October-January
Mature	Primary oocytes in ovary, spermatozoa in testis.	January-February
Preparatory	No morphological changes from mature gonads.	February-March
Spawning	Release of oocytes and spermatozoa.	April-May

Table 22. Documentation of time series data for sea surface temperatures from lighthouse stations in British Columbia.

STZ	Location	Start	End	Notes - No Data[1]
1	Cape St James	Jul 1934	Aug 1992	1938-1942
1	Langara Island	Oct 1936	Mar 2006	Sep 1937-Feb 1940
2	Bonilla Island	Apr 1960	Mar 2006	
2	Egg Island	Mar 1970	Mar 2006	
2	McInnes Island	Jul 1954	Mar 2006	Oct 1954-Dec 1954
3	Pine Island	Jan 1937	Feb 2006	
4	Active Pass	Feb 1967	Mar 2006	
4	Cape Mudge	Nov 1936	Apr 1985	
4	Chrome Island	Apr 1961	Mar 2006	
4	Departure Bay	Sep 1914	Mar 2006	Sep 1932-May 1934; Apr 1983-Dec 1986
4	Entrance Island	May 1936	Mar 2006	
4	Sisters Islet	May 1968	May 2005	
4	West Vancouver	Dec 1979	Dec 1993	
5	Amphitrite Point	Aug 1934	Mar 2006	
5	Cape Beale	Jan 1971	Dec 1998	
5	Kains Island	Jan 1935	Jan 2006	
5	Nootka Point	Aug 1934	Mar 2006	Jul 1953-Mar 1987
5	Race Rocks	Feb 1921	Mar 2006	Jul 1940-Apr 1941
5	Sheringham Point	Apr 1968	Aug 1989	

[1] – Minor occurrences of 1-2 months of missing data for each location are not specifically documented.

Table 23. Mean monthly sea surface temperature (°C) for lighthouse stations in British Columbia.

See Table 22 for documentation of time series. Numbers in parentheses are two standard deviations of the mean.

		Month											
STZ	Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Langara	6.52	6.38	6.53	7.27	8.49	9.89	11.19	11.83	11.82	10.72	8.73	7.31
		(2.34)	(2.12)	(1.87)	(1.76)	(1.77)	(2.02)	(2.17)	(2.31)	(2.54)	(2.10)	(2.26)	(2.06)
1	C St. James	7.52	7.18	7.16	7.65	8.70	10.16	11.69	12.66	11.97	10.08	8.82	8.14
		(2.00)	(1.97)	(1.74)	(1.50)	(1.71)	(1.90)	(2.22)	(2.30)	(2.32)	(1.84)	(1.77)	(1.70)
2	Bonilla	6.58	6.53	6.92	7.89	9.47	11.17	12.25	12.48	11.99	10.64	8.73	7.41
		(2.21)	(1.96)	(1.83)	(1.85)	(2.10)	(2.13)	(2.21)	(2.24)	(2.24)	(1.82)	(2.10)	(2.00)
2	McInnes	6.71	6.61	6.88	7.89	9.62	11.51	12.95	13.55	12.90	10.82	8.65	7.47
		(1.92)	(1.75)	(1.60)	(1.73)	(2.15)	(2.15)	(2.04)	(2.04)	(2.12)	(4.93)	(2.08)	(1.84)
2	Egg	7.37	7.25	7.61	8.49	10.04	11.74	12.77	12.74	11.42	9.97	8.76	7.83
		(1.69)	(1.74)	(1.68)	(1.73)	(2.22)	(2.46)	(2.46)	(2.52)	(5.91)	(1.89)	(1.97)	(1.84)
3	Pine	7.61	7.38	7.51	8.02	8.79	9.52	10.04	10.14	9.90	9.75	9.10	8.14
		(1.42)	(1.49)	(1.48)	(1.52)	(1.54)	(1.38)	(1.41)	(1.40)	(1.56)	(4.35)	(5.96)	(1.43)
4	Mudge	6.97	7.22	7.90	9.28	11.20	13.28	14.47	14.17	12.69	10.62	8.68	7.56
		(2.04)	(1.99)	(2.14)	(2.58)	(3.33)	(3.62)	(3.43)	(3.62)	(3.08)	(2.39)	(2.02)	(1.83)
4	Chrome	7.32	7.28	7.92	9.27	12.05	14.99	17.13	17.29	14.66	11.45	9.29	7.99
		(1.86)	(1.61)	(1.71)	(2.34)	(3.63)	(4.02)	(4.03)	(4.08)	(3.43)	(2.47)	(1.71)	(1.68)
4	Sisters	7.05	7.08	7.72	9.31	12.34	15.27	17.30	17.52	15.03	11.66	9.20	7.82
		(1.56)	(1.40)	(1.59)	(2.34)	(3.41)	(3.24)	(2.88)	(2.91)	(3.09)	(2.42)	(1.63)	(1.50)
4	Entrance	6.97	6.98	7.62	9.23	12.28	14.99	17.18	17.34	14.93	11.51	9.10	7.76
		(2.01)	(1.78)	(1.85)	(2.65)	(3.91)	(4.02)	(3.99)	(4.21)	(3.77)	(2.80)	(1.84)	(1.95)
4	Departure	6.40	6.52	7.47	9.38	12.40	15.37	17.53	17.43	15.00	11.50	8.73	7.12
		(4.46)	(2.18)	(4.36)	(2.83)	(3.59)	(3.74)	(5.94)	(3.71)	(6.14)	(8.45)	(4.25)	(4.33)
4	West Van	6.52	6.77	7.70	8.87	11.63	14.62	16.23	16.74	14.32	11.11	8.80	7.43
		(2.22)	(2.09)	(1.61)	(1.87)	(3.69)	(3.86)	(4.04)	(3.50)	(3.49)	(2.47)	(2.78)	(2.67)
4	Active	7.22	7.27	8.07	9.56	11.58	13.77	15.95	16.08	14.24	11.57	9.47	7.84
		(2.41)	(2.06)	(2.05)	(2.57)	(3.56)	(4.45)	(5.05)	(5.01)	(3.84)	(7.99)	(10.17)	(2.33)
5	Kains	7.71	7.60	7.98	8.92	10.36	11.76	12.87	13.38	13.13	11.45	9.57	8.39
		(2.02)	(1.92)	(1.72)	(1.84)	(2.00)	(2.25)	(2.44)	(2.54)	(2.48)	(2.15)	(2.02)	(1.99)
5	Nootka	6.94	6.94	7.84	9.69	12.01	13.95	15.40	15.93	14.73	11.90	9.08	7.59
		(2.32)	(2.19)	(2.28)	(2.55)	(2.71)	(2.71)	(2.80)	(2.57)	(2.48)	(2.78)	(2.34)	(2.32)
5	Beale	7.82	7.81	8.54	9.78	11.35	12.38	13.23	13.10	12.66	11.07	9.77	8.33
		(2.07)	(2.25)	(2.18)	(2.23)	(2.75)	(2.87)	(2.77)	(2.60)	(2.78)	(2.66)	(2.38)	(2.56)
5	Amphitrite	7.78	7.73	8.33	9.44	10.71	11.79	12.77	13.40	13.02	11.61	10.00	8.66
		(2.16)	(2.10)	(1.86)	(1.89)	(2.31)	(2.31)	(2.48)	(2.13)	(4.33)	(6.88)	(4.58)	(2.12)
5	Sherringham	7.63	7.60	8.03	8.66	9.45	10.35	10.97	11.20	10.89	10.01	9.21	8.29
		(1.45)	(1.64)	(1.65)	(1.45)	(1.55)	(1.55)	(1.50)	(1.67)	(1.44)	(1.55)	(1.64)	(1.43)
5	Race	7.47	7.40	7.79	8.52	9.47	10.29	10.88	11.05	10.70	9.84	8.87	8.04
		(1.38)	(1.51)	(1.55)	(1.50)	(1.63)	(1.70)	(1.70)	(1.59)	(1.41)	(3.78)	(3.90)	(1.34)

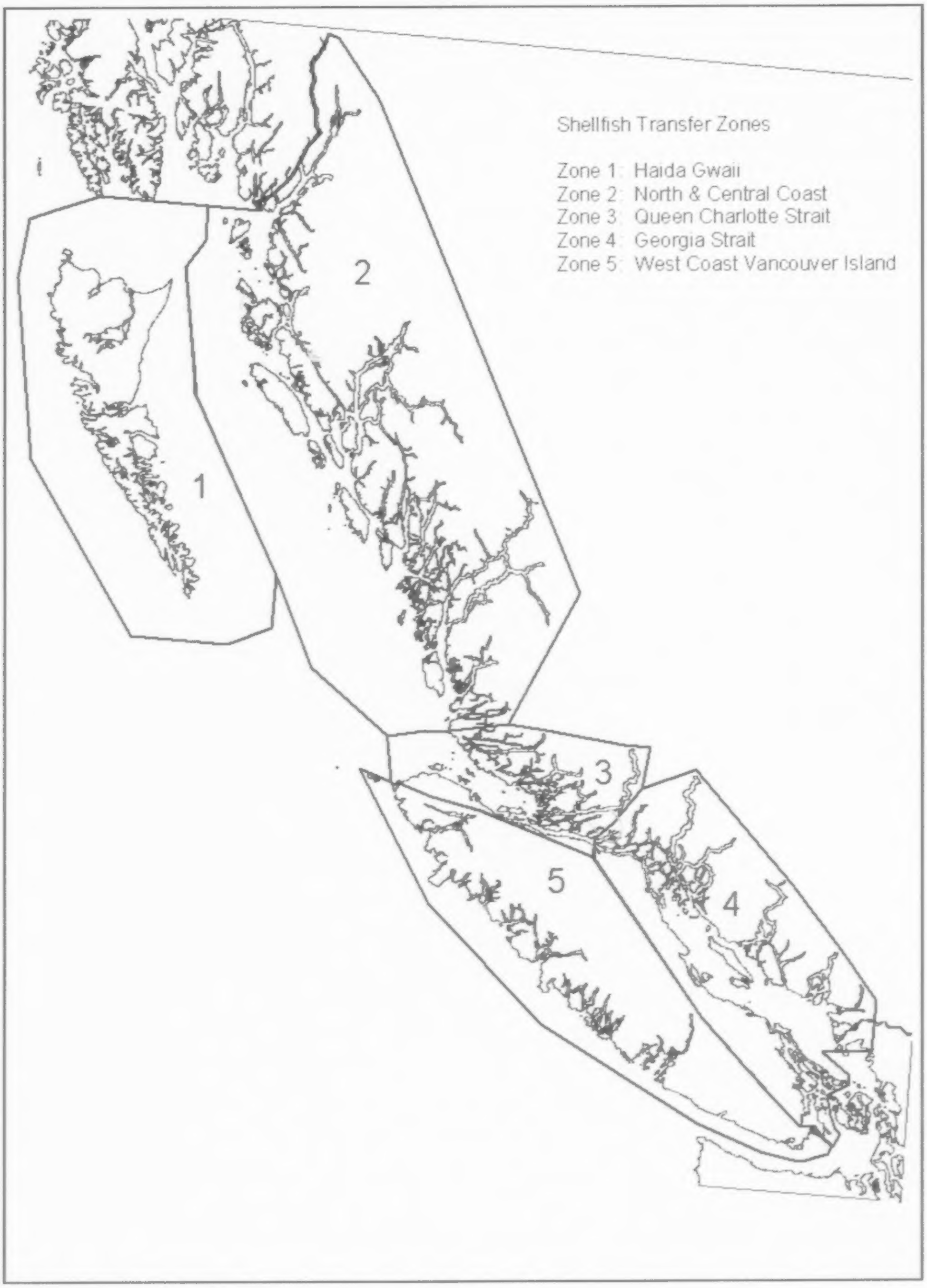
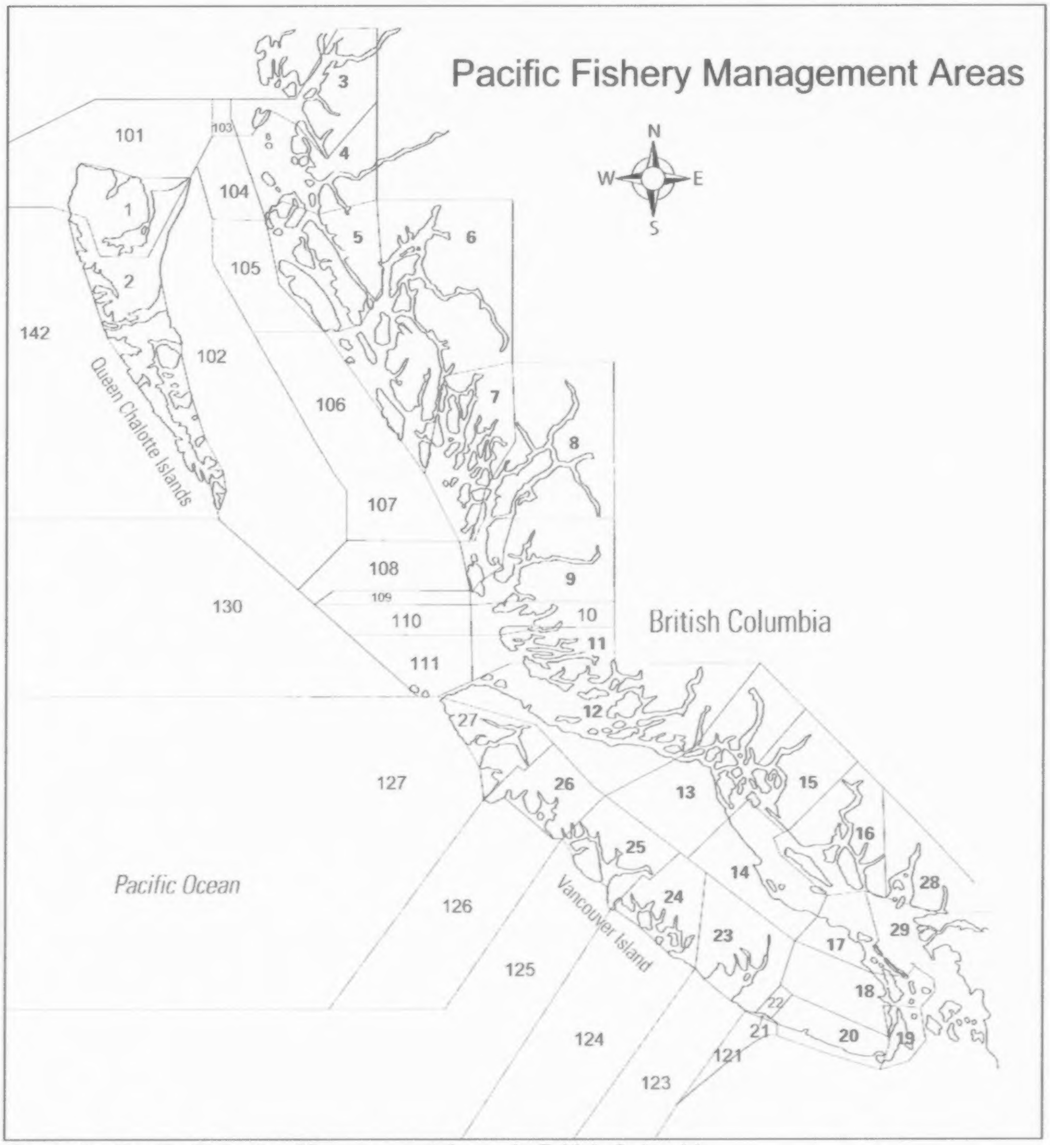

Shellfish Transfer Zones
Zone 1: Haida Gwaii
Zone 2: North & Central Coast
Zone 3: Queen Charlotte Strait
Zone 4: Georgia Strait
Zone 5: West Coast Vancouver Island
1
2
3
4
5

Figure 1. Shellfish Transfer Zones for coastal British Columbia (ITC 2004).


Pacific Fishery Management Areas
N
W
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101
103
4
104
1
5
6
105
2
142
102
Queen Chalotte Islands
106
7
8
107
108
109
130
9
110
10
British Columbia
11
111
12
27
127
26
13
15
25
16
Pacific Ocean
14
24
28
126
Vancouver Island
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124
121
123

Figure 2. Pacific Fisheries Management Areas in British Columbia.

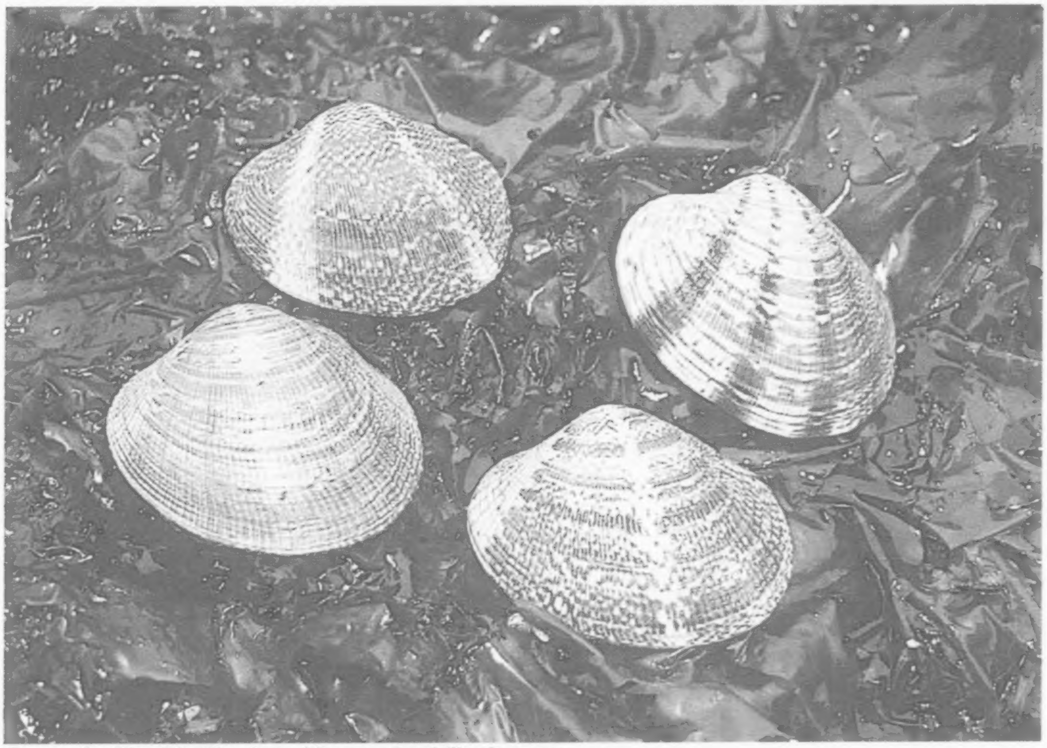


Figure 3. The Manila clam, Venerupis philippinarum.
Photo © Rick Harbo.

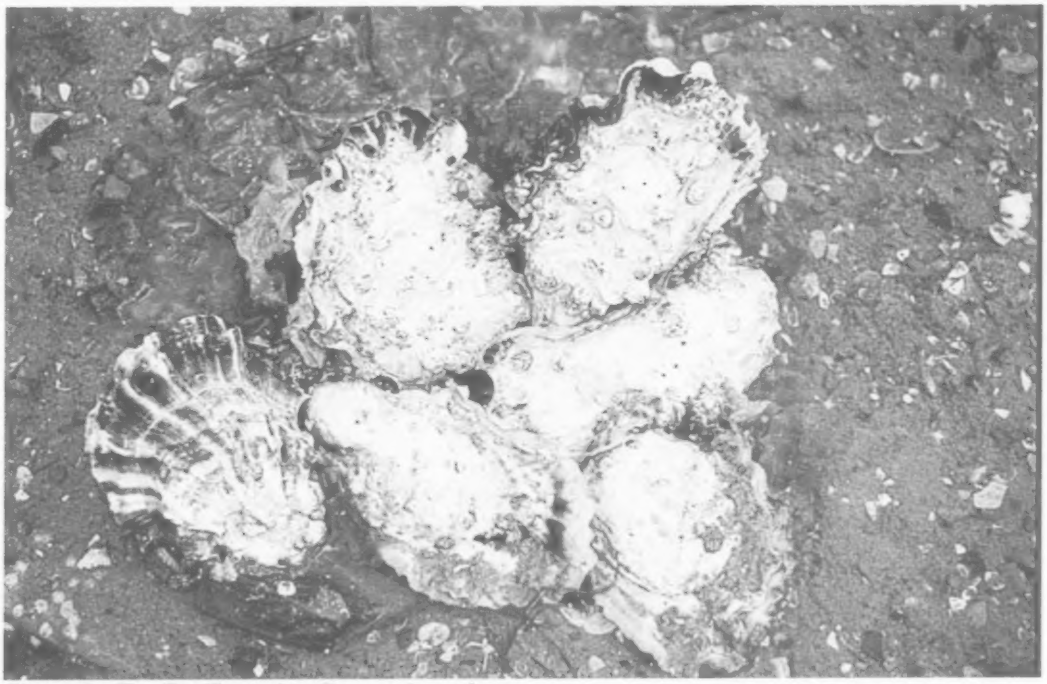


Figure 4. The Pacific oyster, Crassostrea gigas.
Photo © Rick Harbo.

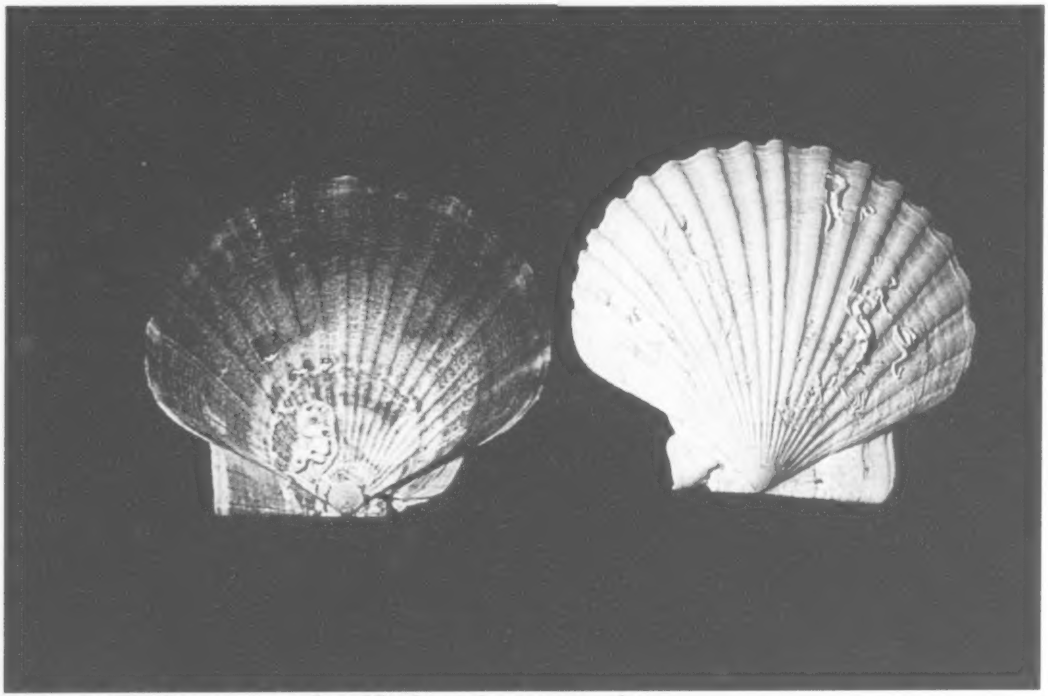
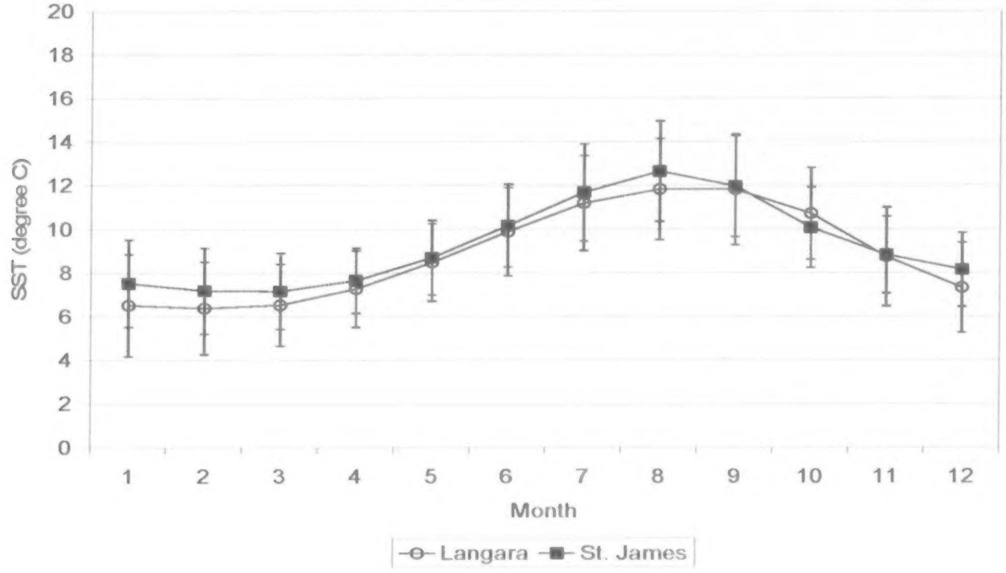


Figure 5. The Japanese scallop, Mizuhopecten yessoensis.
Photo © Rick Harbo.



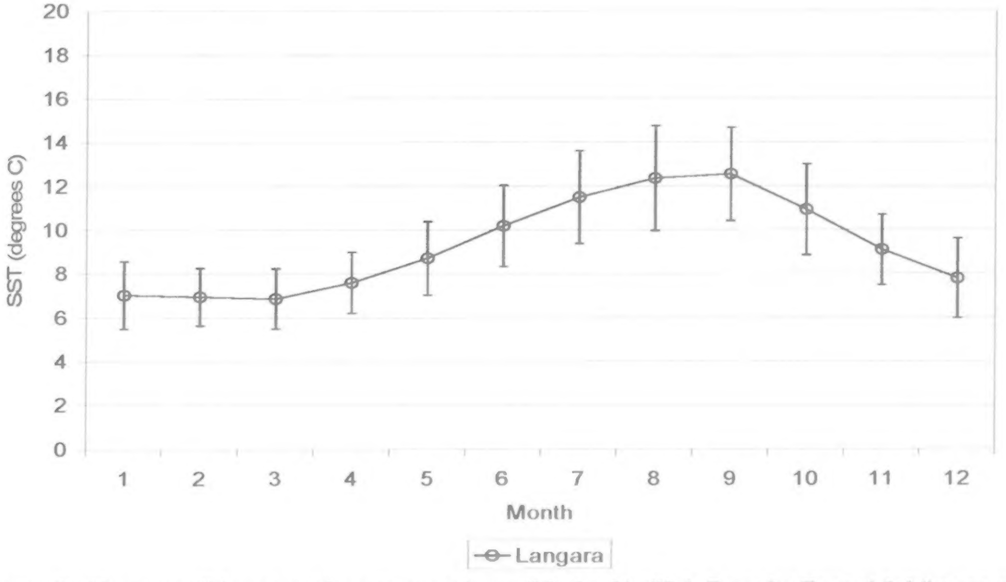


Figure 6. Mean monthly sea surface temperatures (°C) for Shellfish Transfer Zone 1 lighthouse stations at Langara Island and Cape St. James.

See Table 22 for documentation of time series. Upper panel uses entire data set, lower panel only January 1995 to March 2006. Error bars are two standard deviations of the mean.

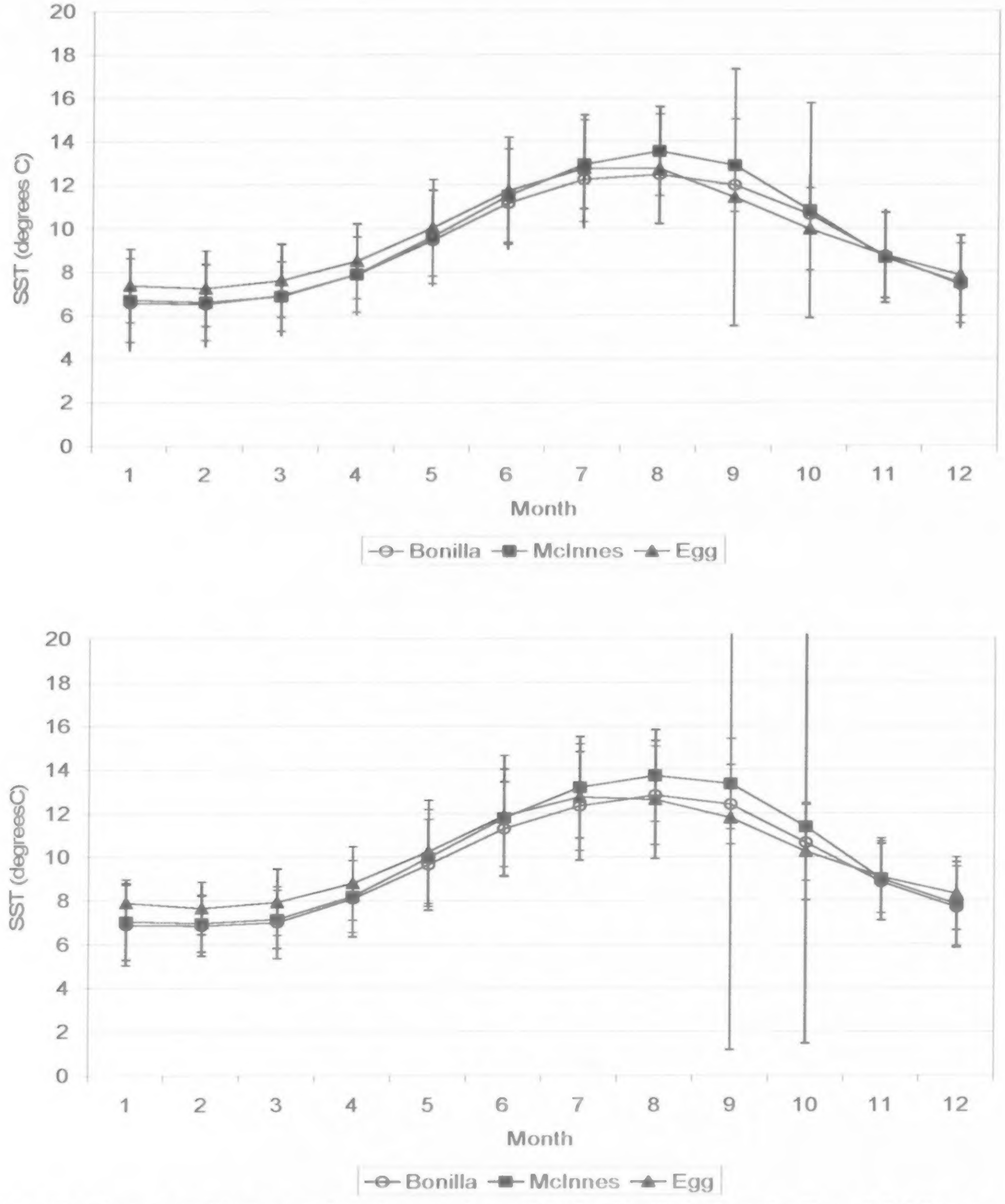


Figure 7. Mean monthly sea surface temperatures (°C) for Shellfish Transfer Zone 2 lighthouse stations at Bonilla Island, McInnes Island and Egg Island.

See Table 22 for documentation of time series. Upper panel uses entire data set, lower panel only January 1995 to March 2006. Error bars are two standard deviations of the mean.

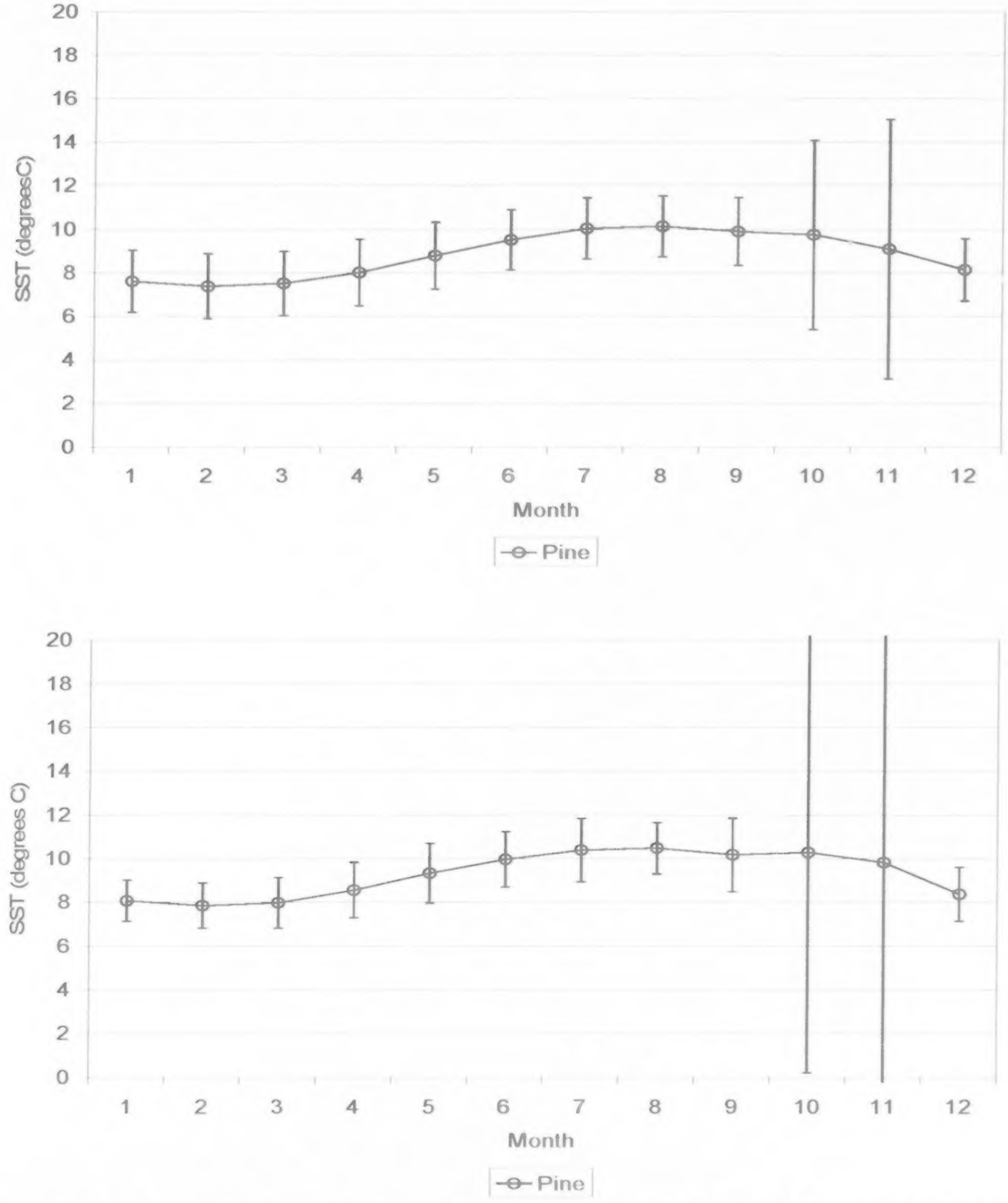


Figure 8. Mean monthly sea surface temperatures (°C) for Shellfish Transfer Zone 3 lighthouse station at Pine Island.

See Table 22 for documentation of time series. Upper panel uses entire data set, lower panel only January 1995 to March 2006. Error bars are two standard deviations of the mean.

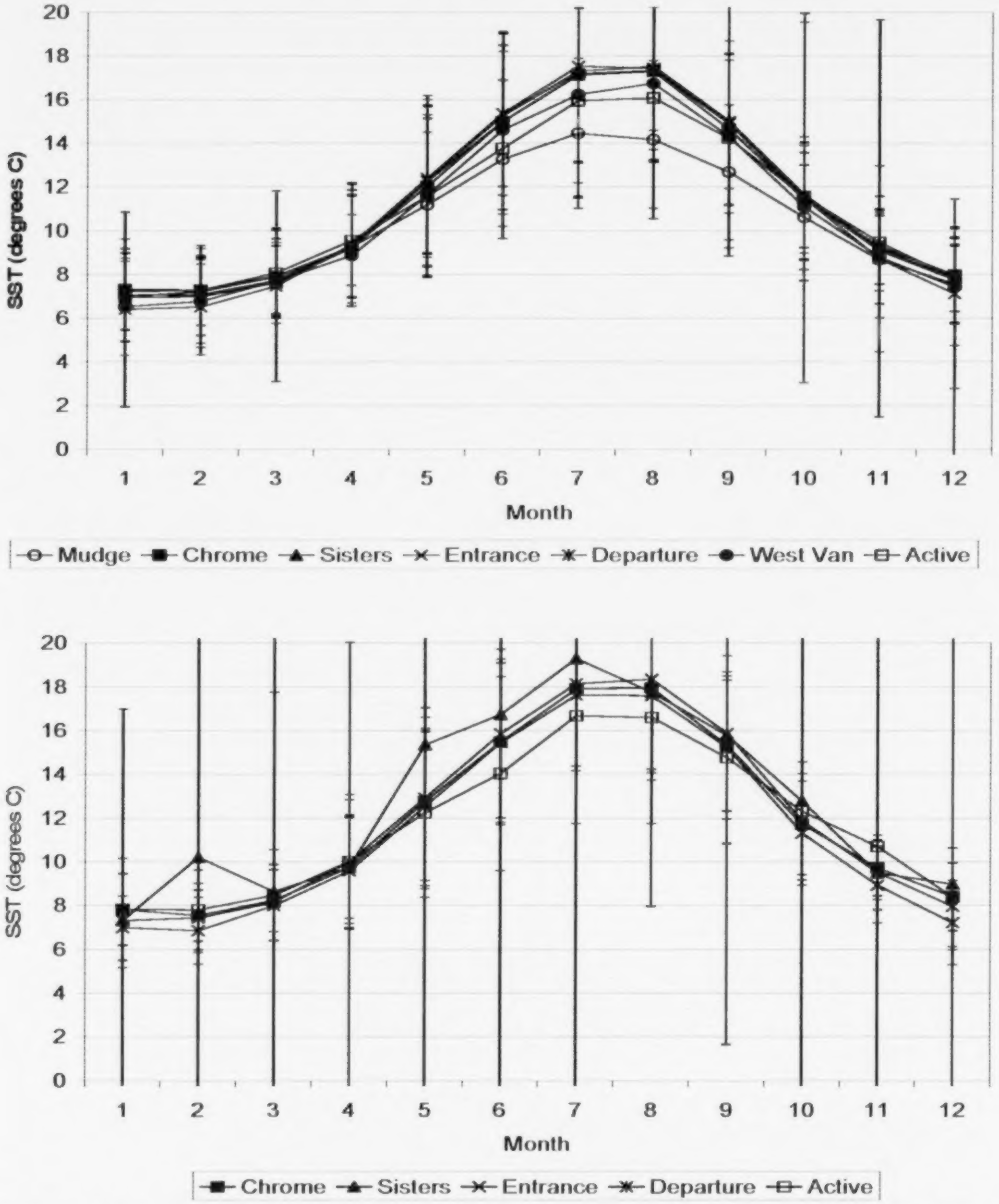


Figure 9. Mean monthly sea surface temperatures (°C) for Shellfish Transfer Zone 4 lighthouse stations at Cape Mudge, Chrome Island, Sisters Island, Entrance Island, Departure Bay, West Vancouver and Active Pass.

See Table 22 for documentation of time series. Upper panel uses entire data set, lower panel only January 1995 to March 2006. Error bars are two standard deviations of the mean.

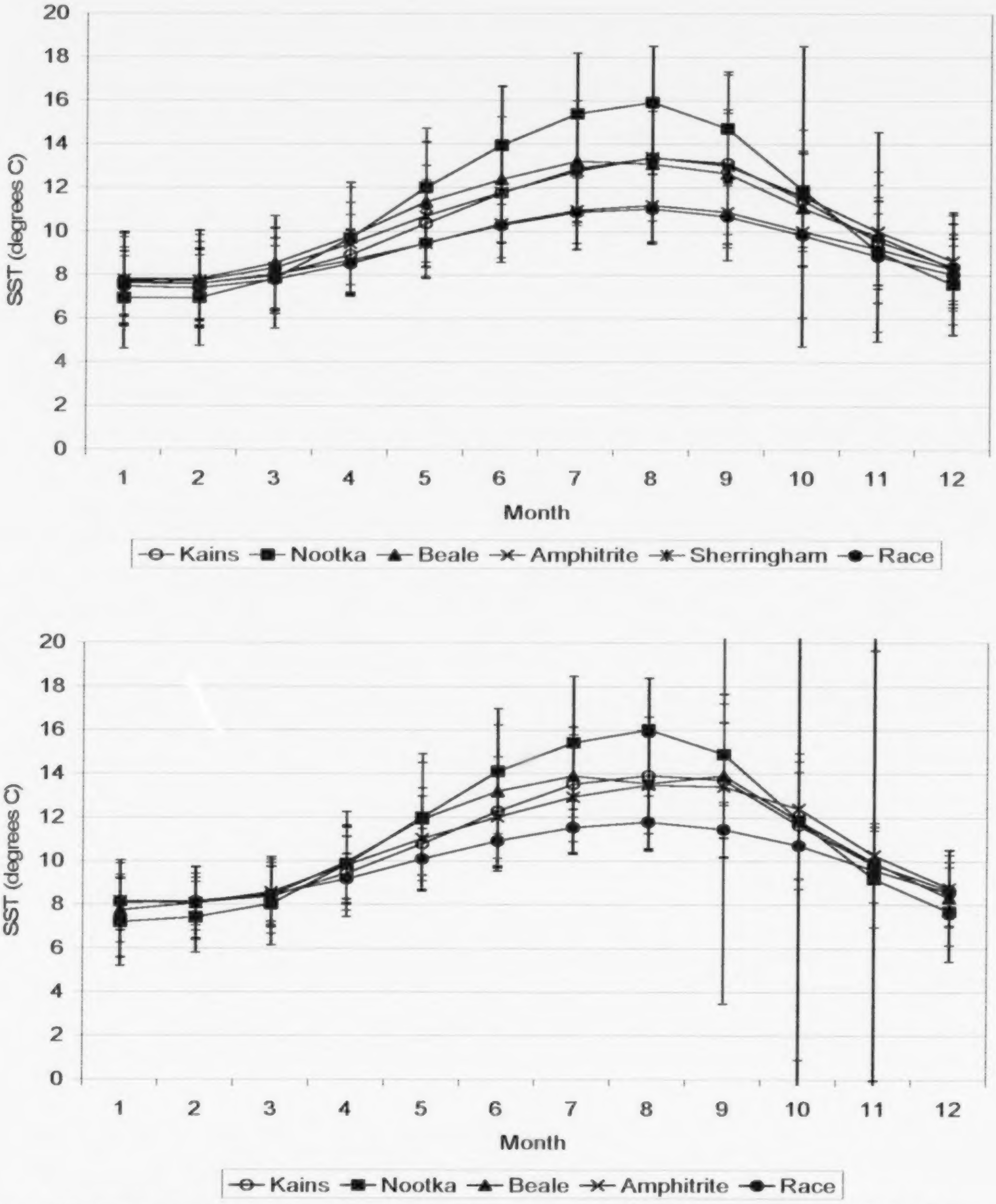


Figure 10. Mean monthly sea surface temperatures (°C) for Shellfish Transfer Zone 5 lighthouse stations at Kains Island, Nootka Point, Cape Beale, Amphitrite Point, Sherringham Point and Race Rocks.

See Table 22 for documentation of time series. Upper panel uses entire data set, lower panel only January 1995 to March 2006. Error bars are two standard deviations of the mean.

APPENDIX 1 - PSARC REQUEST FOR WORKING PAPER[8]

Date Submitted: April 2005

Individual or group requesting advice:
(Fisheries Manager/Biologist, Science, SWG, PSARC, Industry, Other stakeholder etc.)

DFO Science, DFO Fisheries and Aquaculture Management, Federal/Provincial Introductions and Transfers Committee

Proposed PSARC Presentation Date:
November, 2005

Subject of Paper (title if developed):

Risk assessment of introductions and transfers of selected exotic bivalves to and within British Columbia.

Science Lead Author(s):

S. Bower, R. Withler, G. Gillespie, D. Kieser

Resource Management Lead Author:

K. Marcus

Rationale for request:
(What is the issue, what will it address, importance, etc.)

The National Code on Introductions and Transfers of Aquatic Organisms provides direction on information requirements and decision rules for completion of a risk assessment for movements of exotic shellfish into or within British Columbia. The requirement for formal risk assessment is also included in the draft Guidelines for Shellfish Introductions and Transfers in British Columbia, produced by the Federal/Provincial Introductions and Transfers Committee. To date risk assessments have been carried out on a case-by-case basis, and none have passed through the scientific peer review process of PSARC. If the advice provided through the ITC is to be science based, then it must be peer reviewed.

Shellfish aquaculture activities are rapidly expanding beyond the Strait of Georgia to the west coast of Vancouver Island and the British Columbia's northern coastal areas. Many of these aquaculture tenures are established to culture exotic species. FAM and I&TC staff are receiving applications to move exotics to various area or zones of the coast and are pressured to make decisions with little or no data. There are questions and concerns regarding the range of exotics already naturalised in BC and potential impacts on fish habitat, indigenous species health and genetics, and the ecosystem.

Because the National Code was not signed until 2003, basic impact assessment information has not been compiled and reviewed for any of the exotic species currently utilized in aquaculture in British Columbia (Manila clam, *Venerupis philippinarum*; Pacific oyster, *Crassostrea gigas*; European flat oyster, *Ostrea edulis*; Kumamoto oyster, *Crassostrea*

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[8] Once completed and agreed to by leads forward to the PSARC secretariat for routing to appropriate RD. Append approved RFWP to Working Paper.

sikamea; Atlantic blue mussel, *Mytilus edulis*, Mediterranean mussel. *Mytilus galloprovincialis*; and Japanese weathervane scallop, *Mizuhopecten yessoensis*). The proposed paper would provide peer-reviewed biological information and baseline impact assessments for these species within the context of the National Code.

By undertaking a comprehensive review of these species now, information on their impact on indigenous species as well as other exotic species cultured by the aquaculture industry in BC can be assessed and the approach can serve as a model system when there are requests for additional exotic species. The PSARC process can also refine the questions to be answered during a National Code required risk assessment.

Objective of Working Paper including assessment of environment/climate impacts:
(To be developed by FM, StAD, Habitat Science, HEB/Oceans, Ocean Science and Productivity)

To provide biological information and baseline impact assessments for the following exotic species within the context of the National Code:
Clams: Manila clam, *Venerupis philippinarum*;
Oysters:Pacific oyster, *Crassostrea gigas*; European flat oyster, *Ostrea edulis*; Kumamoto oyster, *Crassostrea sikamea*, Atlantic oyster, *Crassostrea virginica* (naturalized population in the estuaries of the Nikomenkl River and Boundary Bay)
Mussels: Atlantic blue mussel, *Mytilus edulis*, Mediterranean mussel. *Mytilus galloprovincialis*; and Scallops: Japanese weathervane scallop, *Mizuhopecten yessoensis*.(and hybrids with Patinopecten)

Question(s) to be addressed in the Working Paper:
(To be developed by initiator)

For each species,
1. summarize from the literature:

> Taxonomy; description; history in aquaculture, enhancement or other introductions; life history (native range, previous introductions and associated ecological effects; limiting factors within the natural range; physiological tolerances; habitat preferences; reproductive biology; migratory behaviour; food preferences; growth rate and life span; pathogens and parasites.

2. Where information exists, address other elements of the National Code risk assessment framework, in particular:

> Potential for survival and establishment in the event of escape; habitat occupation and overlap with vulnerable, threatened or endangered species;(for instance: There is concern for competition for space and food between the native Olympia oyster, *Ostrea conchaphila*, currently a COSEWIC-listed species of concern, and the European flat oysters *Ostrea edulis;* niche overlap with native species; trophic relations and impacts of the introduced species; potential for survival and reproduction in receiving environment; potential for hybridization; potential for local extinction of native species of stocks due to introduction.

3. Provide information and discussion whether the biological zones outlined in the draft Regional policy are appropriate for the species under review with consideration of ecological and genetic impacts of proposed transfers. (The proposed zones are based primarily on disease concerns.)

Stakeholders Affected:

Aquaculture industry, commercial and recreational fishers, First Nations, DFO Resource and Habitat Managers, the Province of British Columbia

How Advice May Impact the Development of a Fishing Plan:

FAM and the I&TC will use the information of the PSARC paper as a basis to provide advice to the Province of BC in the aquaculture referral process, and in decision making by the I&TC for Section 56 transfer permits. Commercial fishery management plans will not be directly affected.

Timing Issues Related to When Advice is Necessary:

Aquaculture development initiatives are well underway through BC's shellfish aquaculture expansion initiative and in support of First Nations treaty related initiatives. The advice is required now.

Initiating sector approval:

Regional Director, Science: ______________________; Date:______________________

Regional Director, FAM: ______________________; Date:______________________